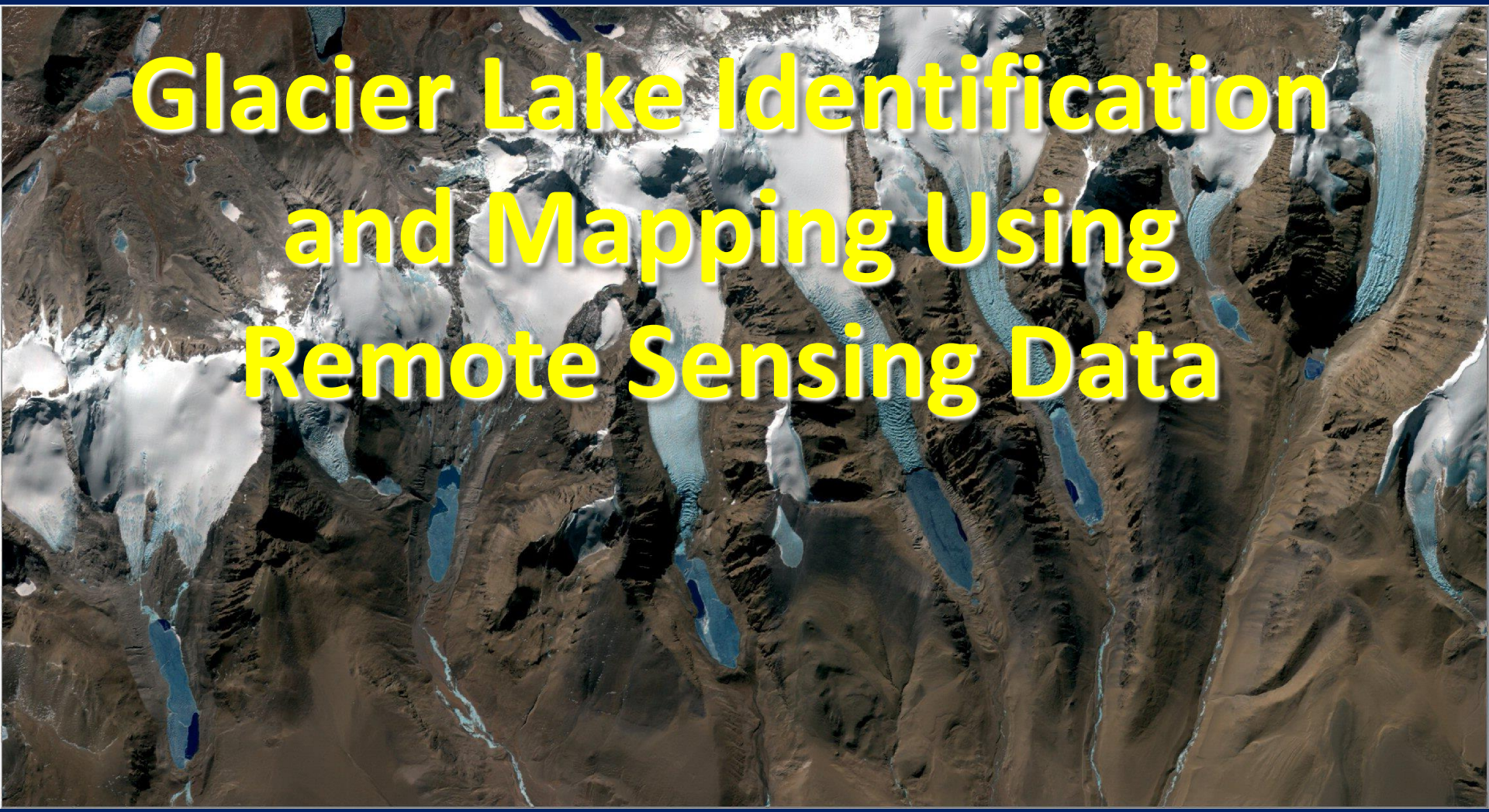

Glacier Lake Identification and Mapping Using Remote Sensing Data

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Engineer'G' & Head, WRAD
Water Resources Group
National Remote Sensing Centre

Glacier Lake Identification and Mapping Using RS Data

Presentation Outline

- *Introduction to Remote Sensing*
- *Identification of Glacier Lakes (Optical RS data)*
- *Identification of Glacier Lakes (Microwave RS data)*
- *Monitoring of Glacier Lakes*
- *Updated Database of Himalayan Glacier Lakes*

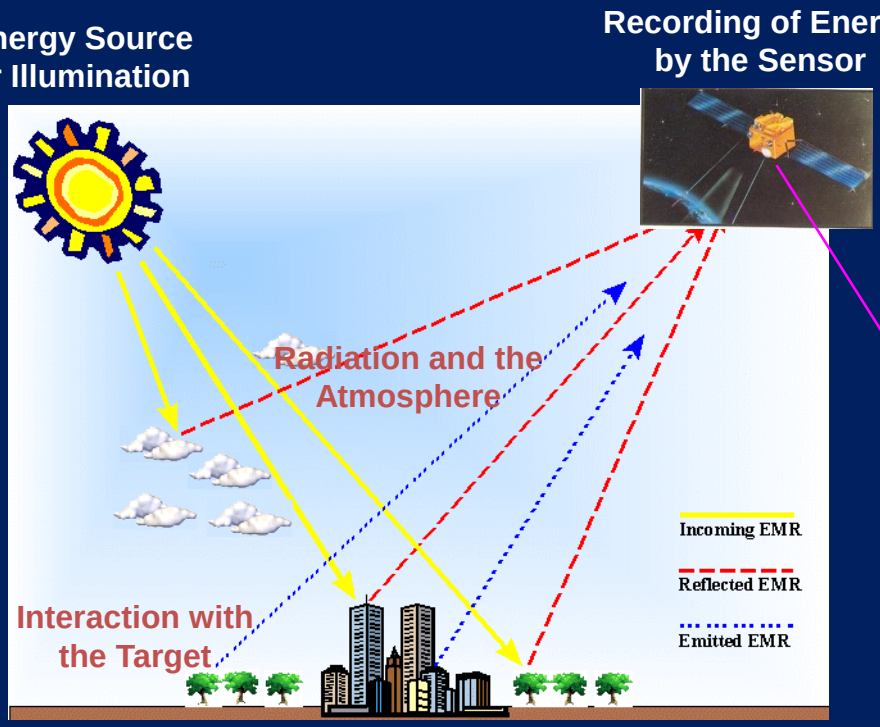
Brief

Introduction to Remote Sensing

Glacier Lake Identification and Mapping Using RS Data

Remote Sensing

Remote Sensing is the technology of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in physical contact with the object, area or phenomenon under investigation and deriving information about them.



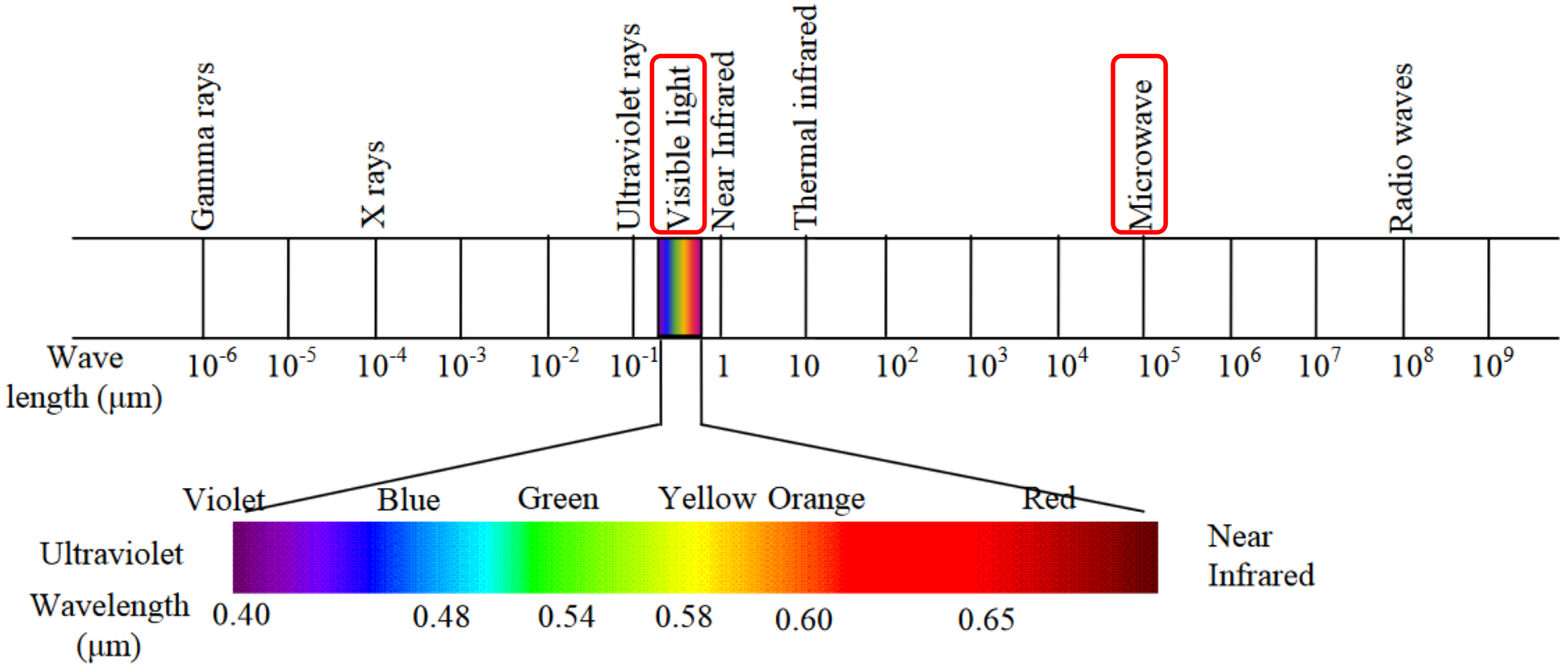
Transmission

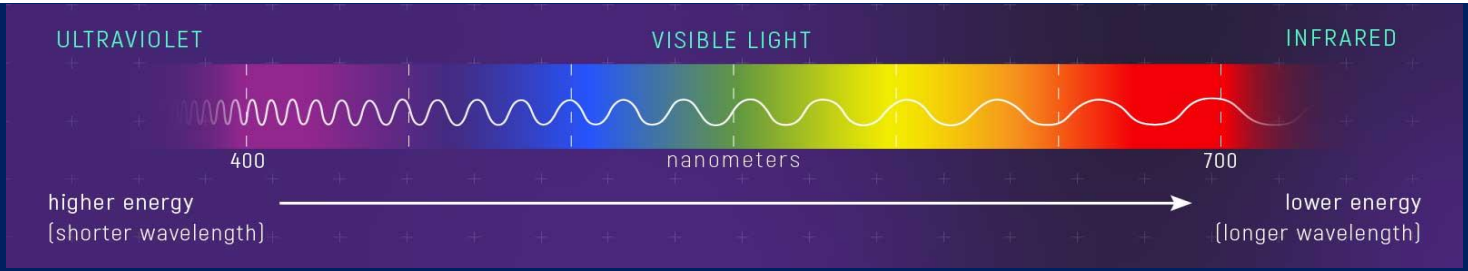
The process of Remote Sensing

Reception & Processing

Interpretation, Analysis & Application

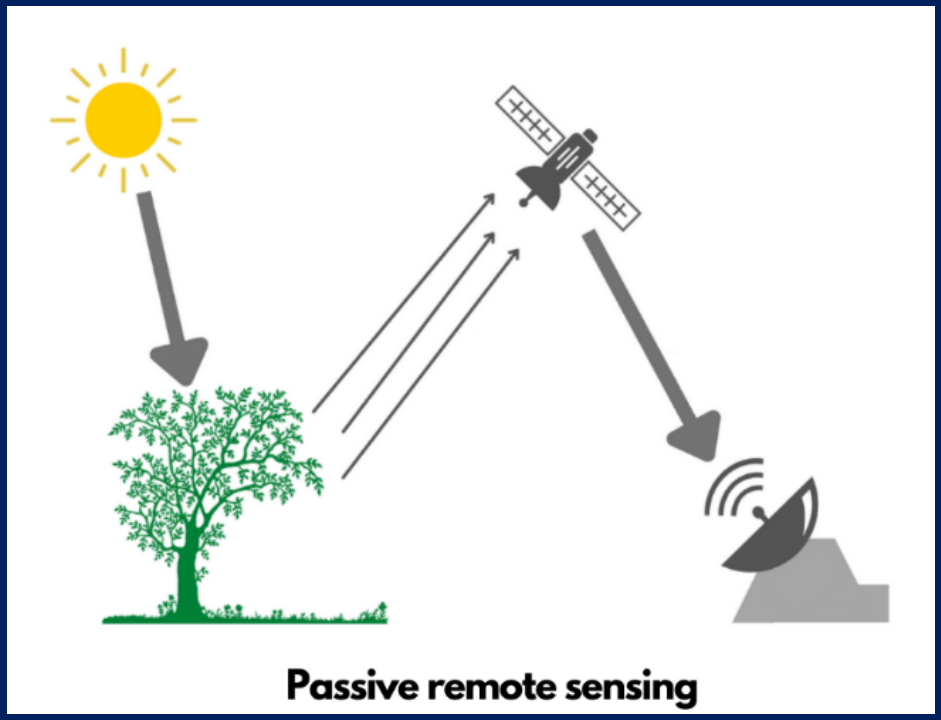
The Electromagnetic Spectrum

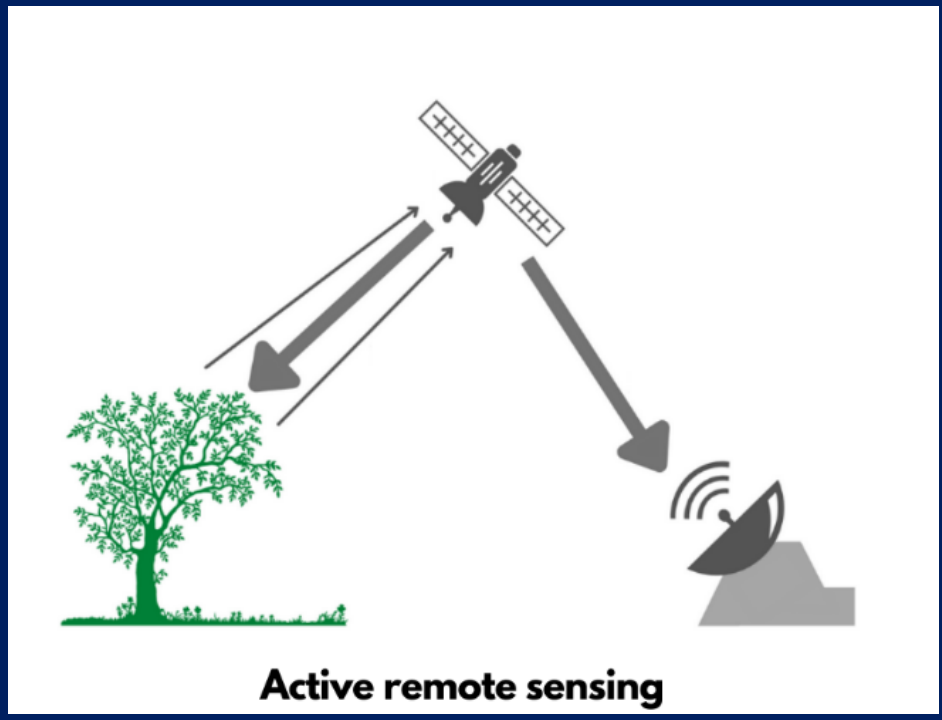




Glacier Lake Identification and Mapping Using RS Data

Passive and Active Sensors



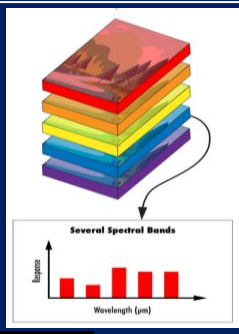


- **Passive sensors** detect sunlight radiation reflected from the earth and thermal radiation in the **visible and infrared of the electromagnetic spectrum**.

- **Active sensors** (example: Radar) **emit own source of radiation to monitor the earth surface or atmospheric features**.
  - Weather independent: microwave radiation can penetrate clouds, light rain and snow.
  - Sunlight independent: can be operated day and night

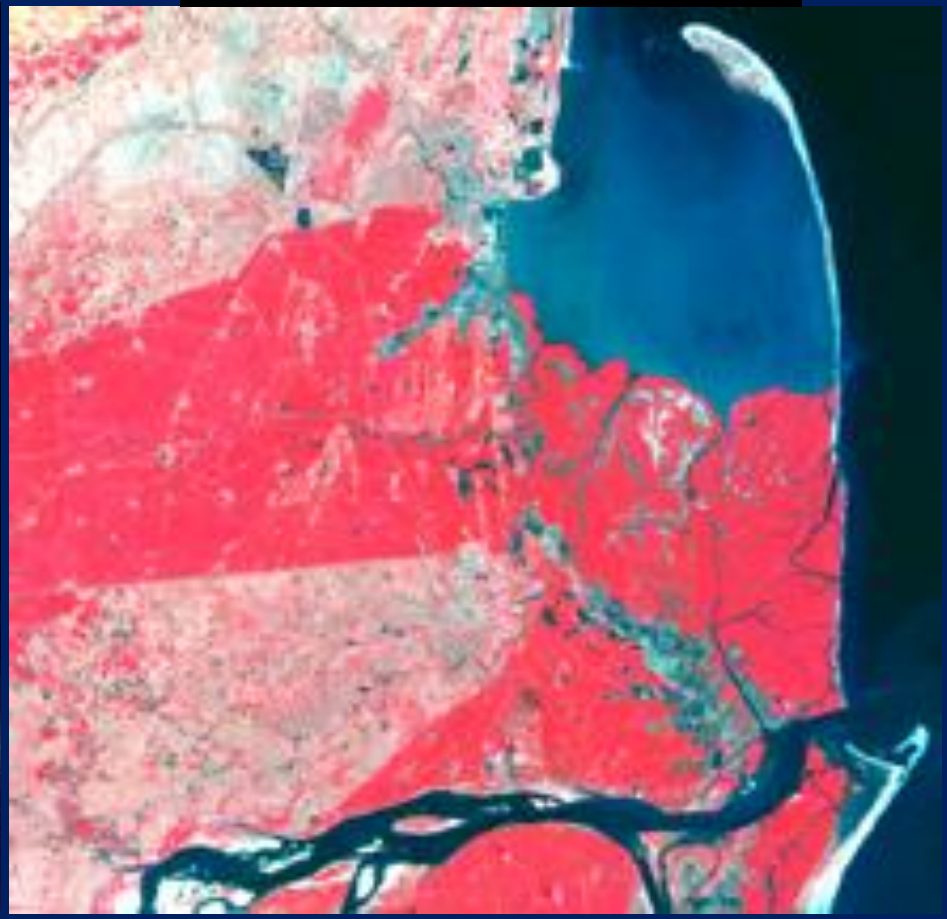
Glacier Lake Identification and Mapping Using RS Data

Optical Imaging



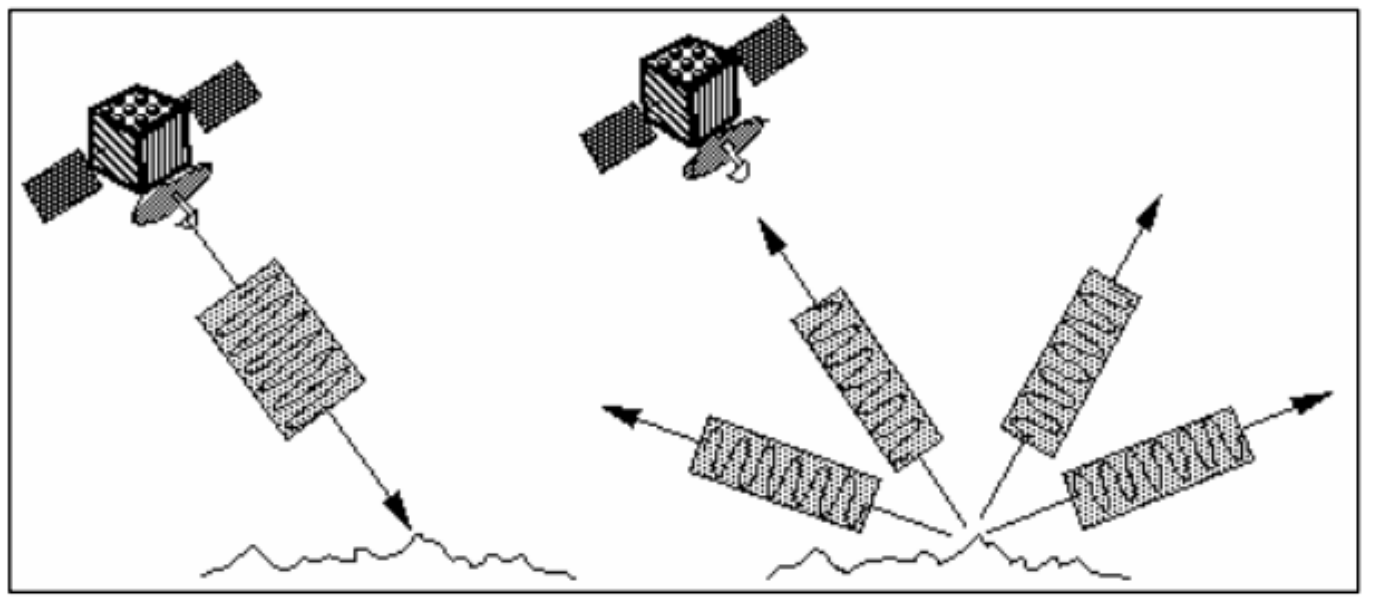
Natural Colour Composite (321)

False Colour Composite (432)

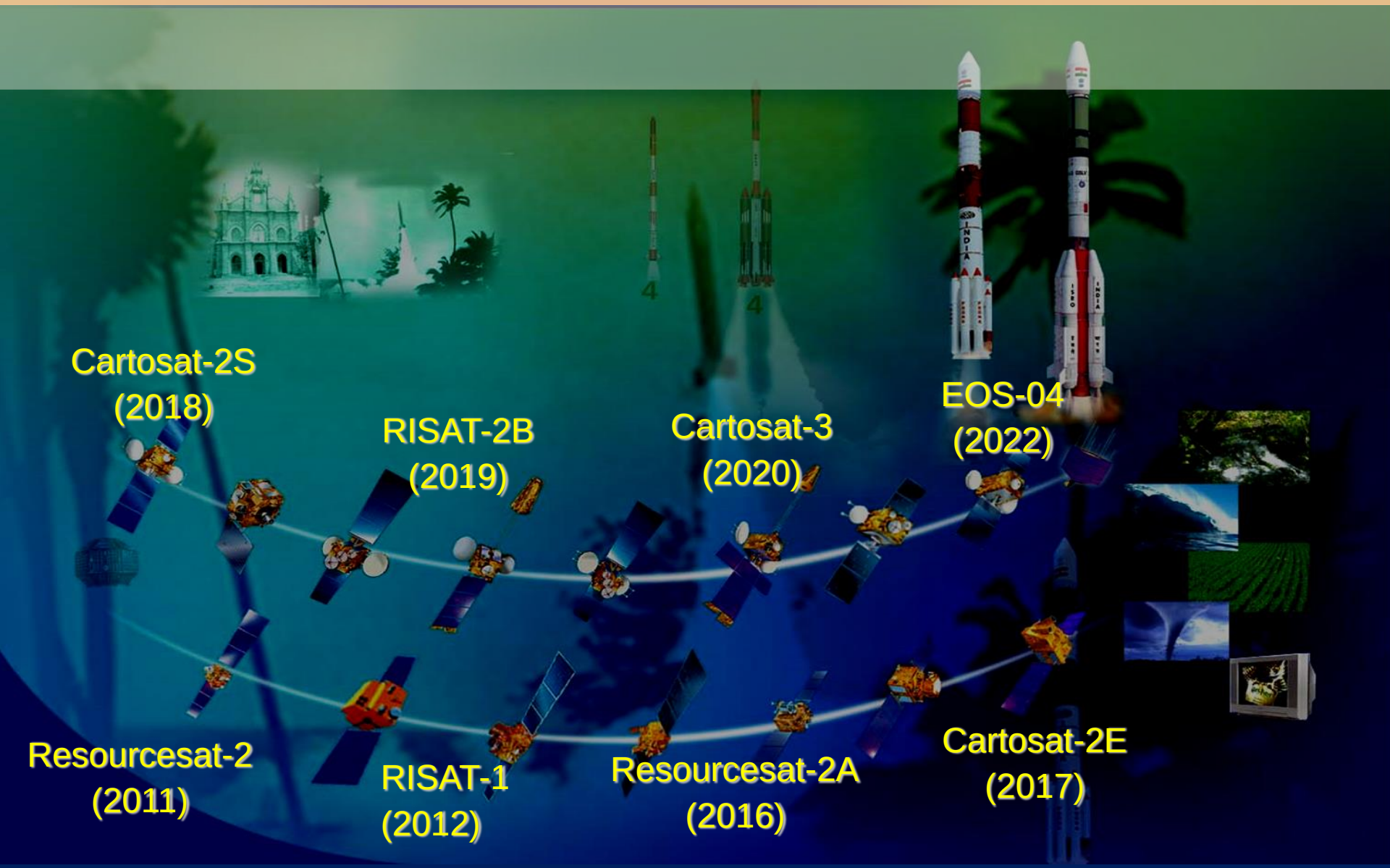


Microwave (SAR) Imaging

- Imaging Radar is an active illumination sensor system.
- An antenna mounted on top of a satellite transmits an intense pulsed signal towards the earths surface in side looking direction.
- The pulse upon striking the targets, scatters in multiple directions depending on the geometry and surface roughness.
- The direct return signals called the back-scatterers are measured in magnitude and phase to reconstruct the image.

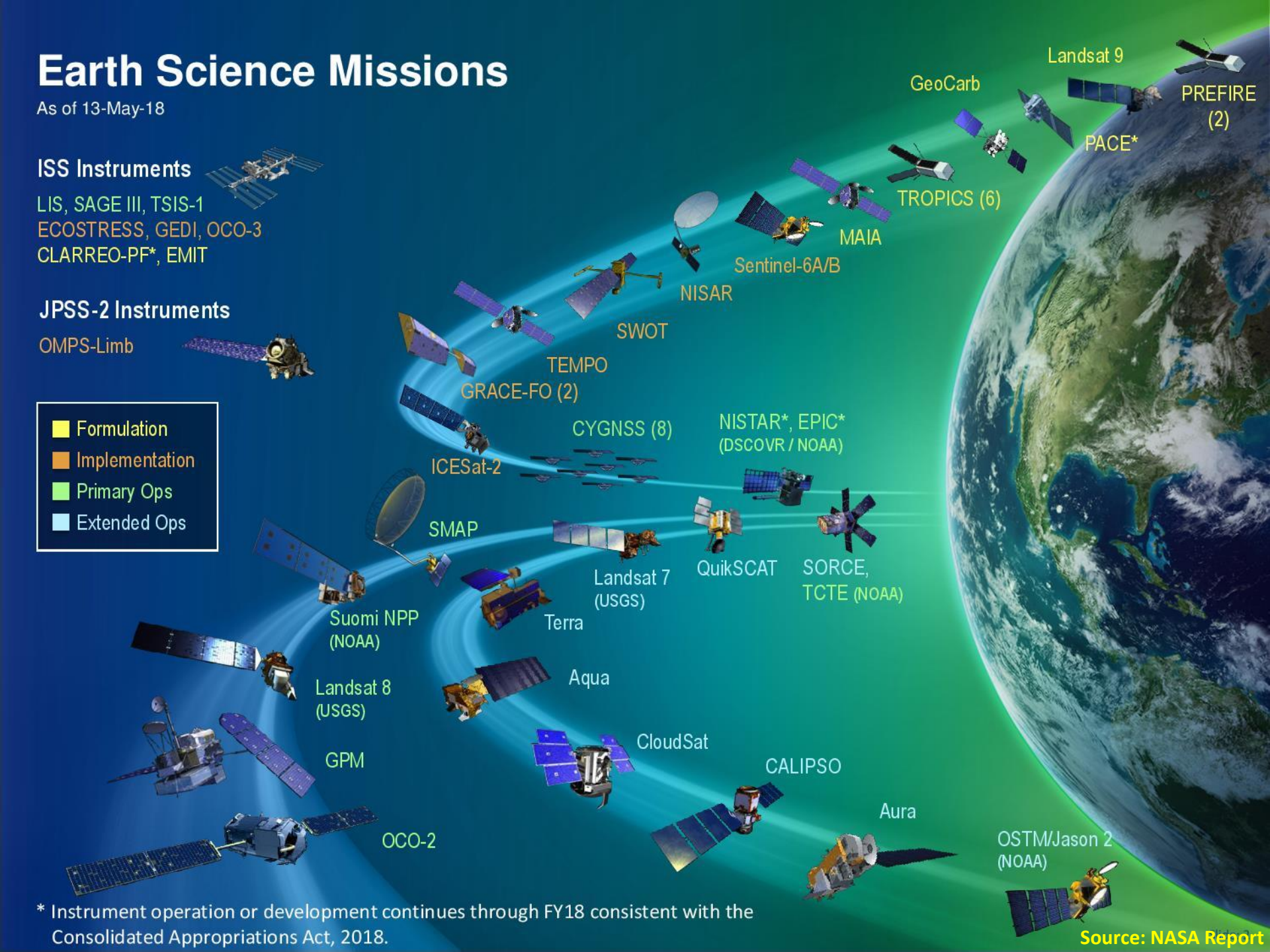


A Constellation of Indian Earth Observation Satellites



Earth Science Missions

As of 13-May-18



* Instrument operation or development continues through FY18 consistent with the Consolidated Appropriations Act, 2018.

Source: NASA Report

Glacier Lake Identification and Mapping Using

Optical RS Data

Glacier Lake Identification and Mapping Using RS Data

Glacier Lake

A glacier lake is defined as a water mass existing in a sufficient amount and extending with a free surface beside and/or in front of a glacier and originated by glacier activities and/or retreating processes of a glacier.

Glacier Lake Identification and Mapping Using RS Data

- Glacial lakes associated glaciers are common in high mountain areas like Himalayas

- As the glaciers recede, new glacial lakes are forming and existing glacial lakes are expanding

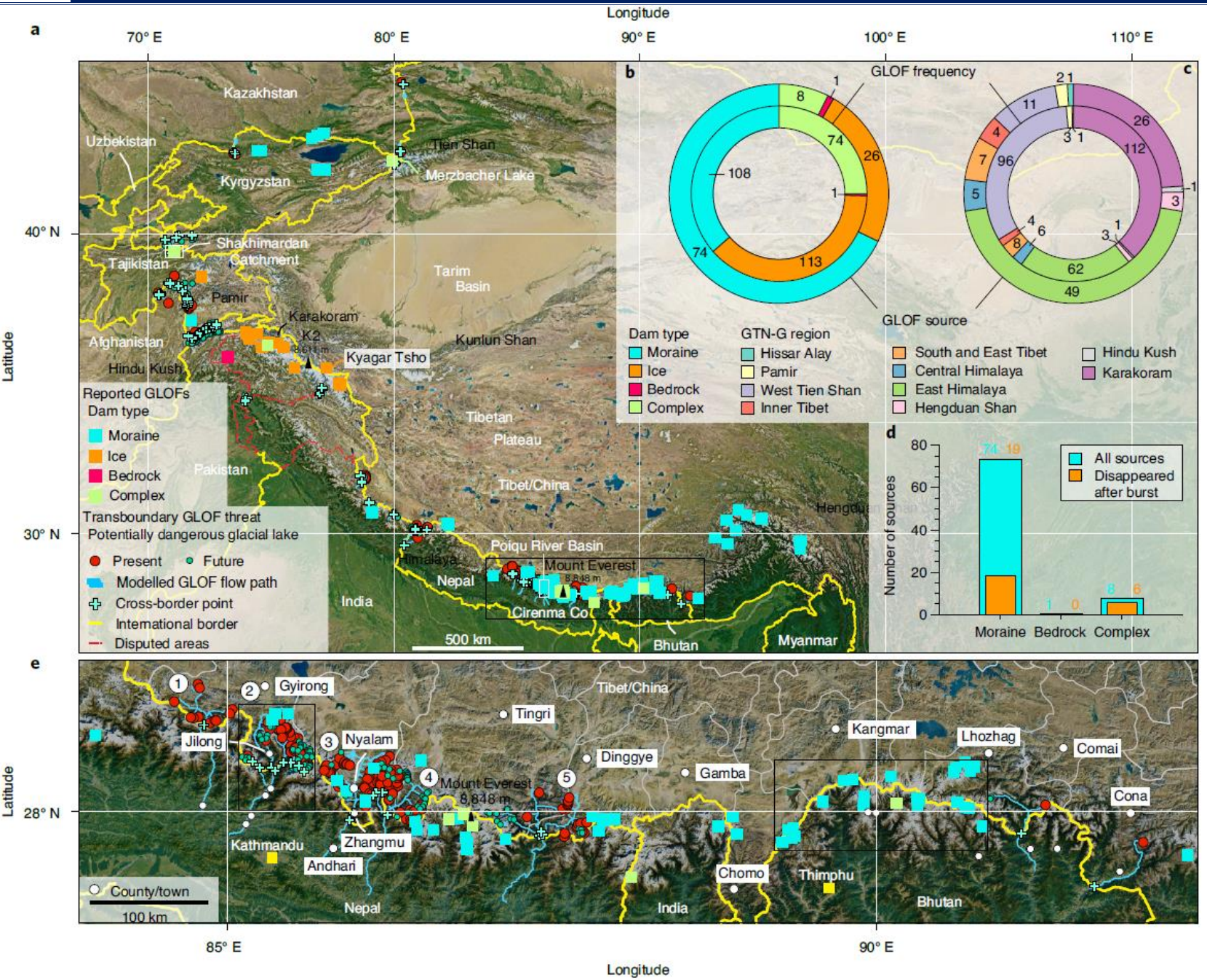
- At times glacial melt water stored in these glacial lakes suddenly gets released causing the flash floods called Glacial Lake Outburst Floods (GLOF)

- These flash floods create havoc to the downstream areas of the river reach affecting people and infrastructure like roads, hydropower plants, agriculture, etc.

- Many GLOF events happened in the Himalayas and increasing in trend




Glacier Lake Identification and Mapping Using RS Data



Historic GLOF events

Source: Zheng et al (2020), Increasing risk of glacial lake outburst floods from future Third Pole deglaciation

Glacier Lake Identification and Mapping Using RS Data

Factors contributing to GLOF of moraine-dammed glacial lake include:

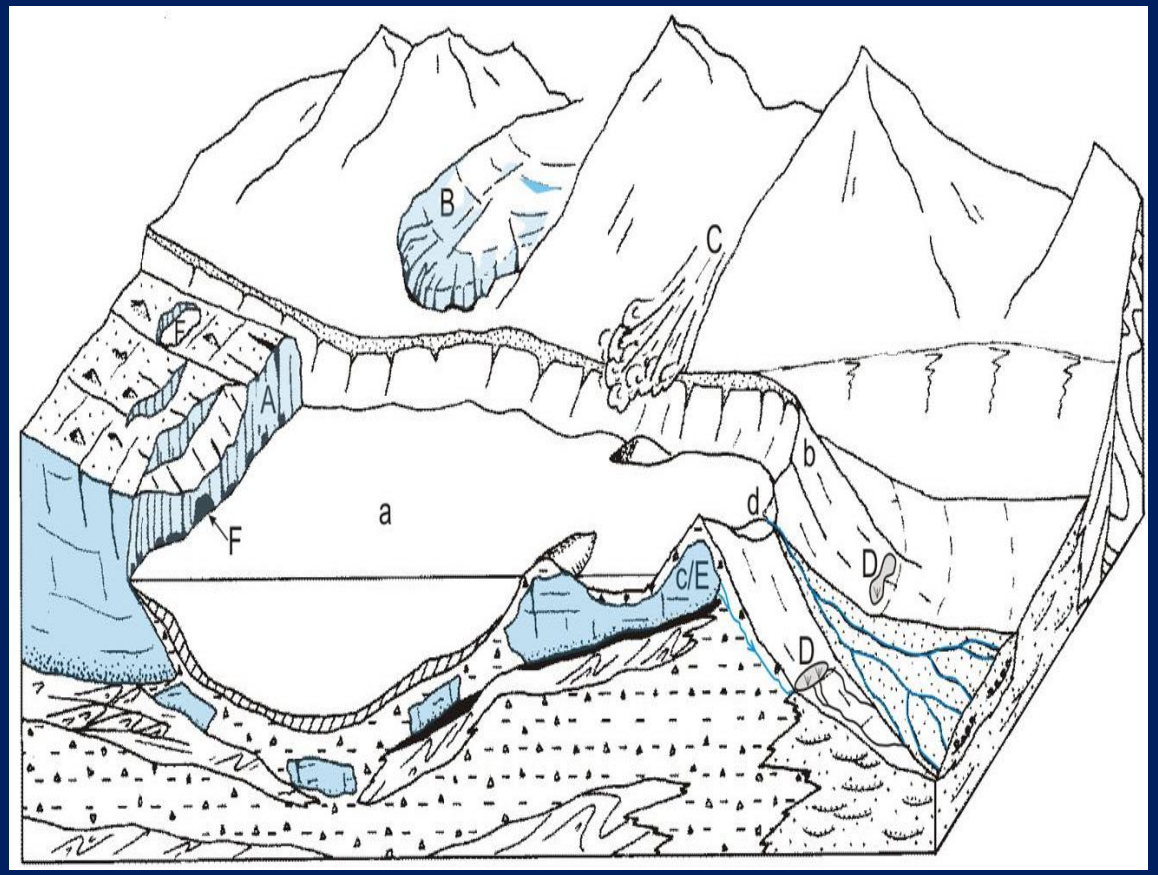
a. Large lake volume
b. Narrow and high moraine dam and condition of material
c. Stagnant glacier ice within the dam and
d. Limited freeboard between the lake level and the crest of the moraine ridge.

Potential outburst flood triggers include avalanche displacement waves from

A. Calving glaciers
B. Hanging glaciers
C. Rock falls
D. Settlement and/or piping within the dam
E. Melting ice-core and
F. Catastrophic glacial drainage into the lake from subglacial or englacial channels or supraglacial lakes

External Triggering Events

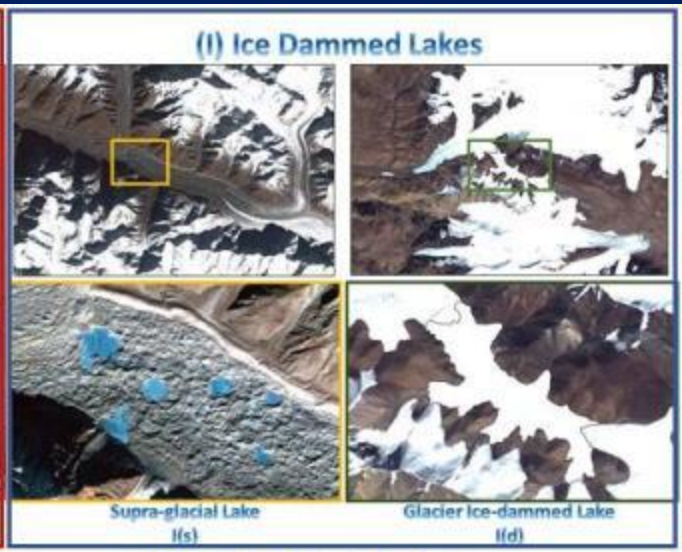
- Cloud burst
- Earth quake

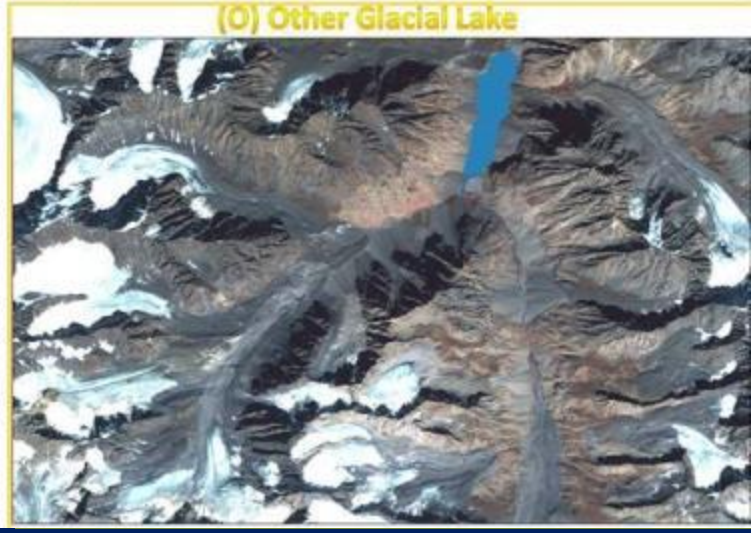


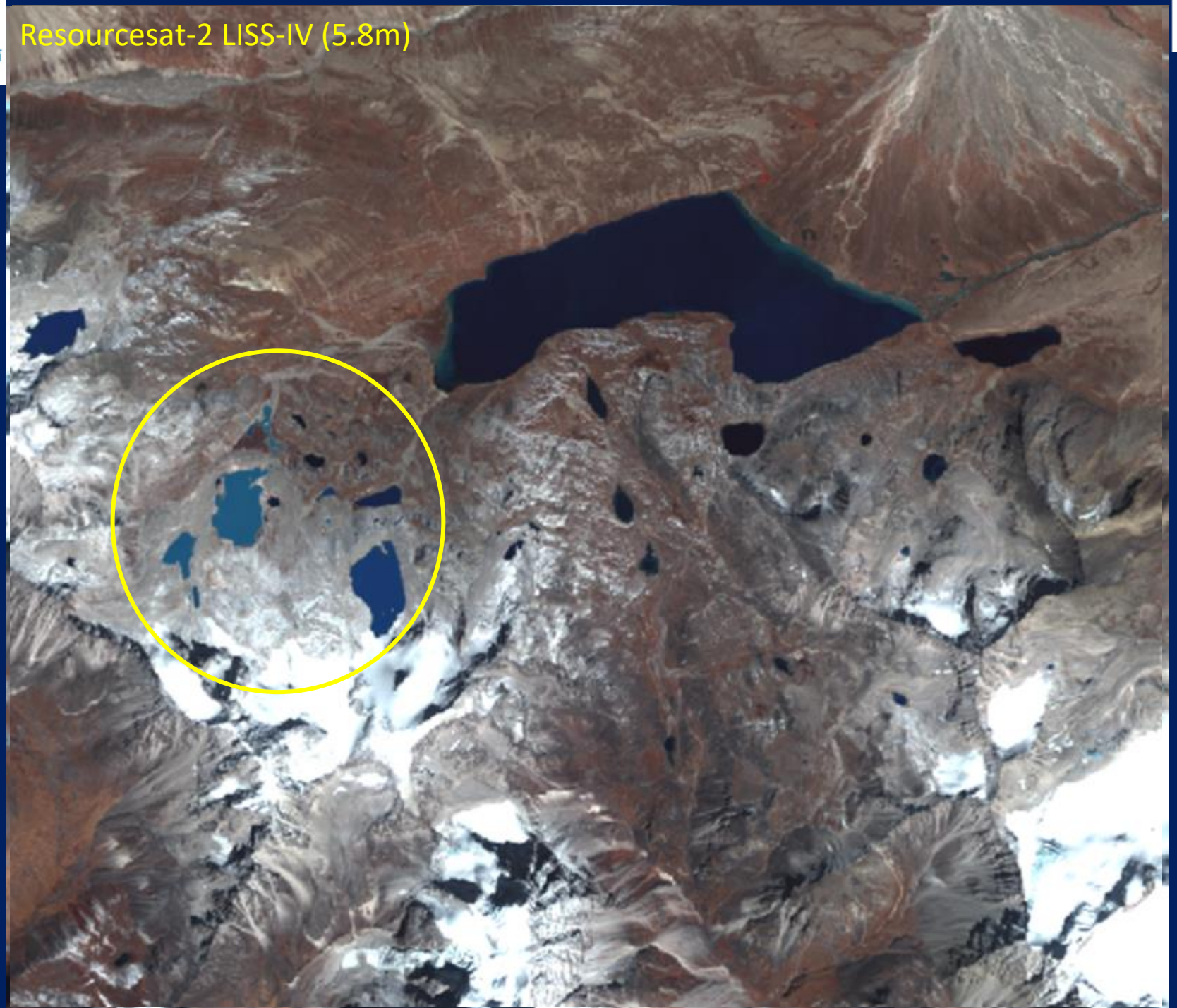
(Source: Richardson, S.D. and J.M. Reynolds (2000)

Glacier Lake Identification and Mapping Using RS Data

Type of Glacial Lakes



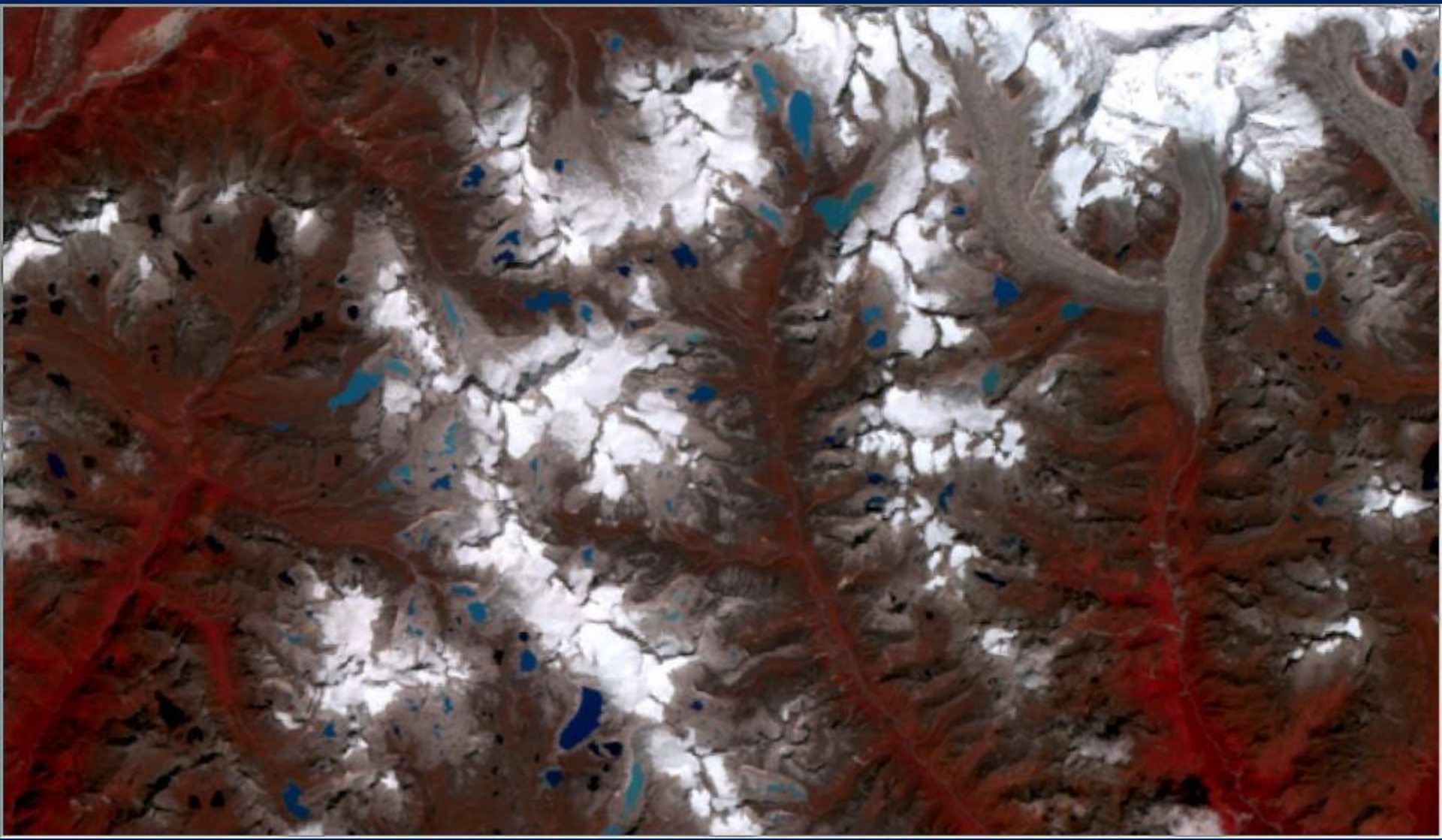



Resourcesat-2 LISS-IV (5.8m)

Glacier Lake Identification and Mapping Using RS Data

Inventory of Glacial Lakes

Glacial Lakes as seen on RS-2 AWiFS satellite image of 07-Oct-2012

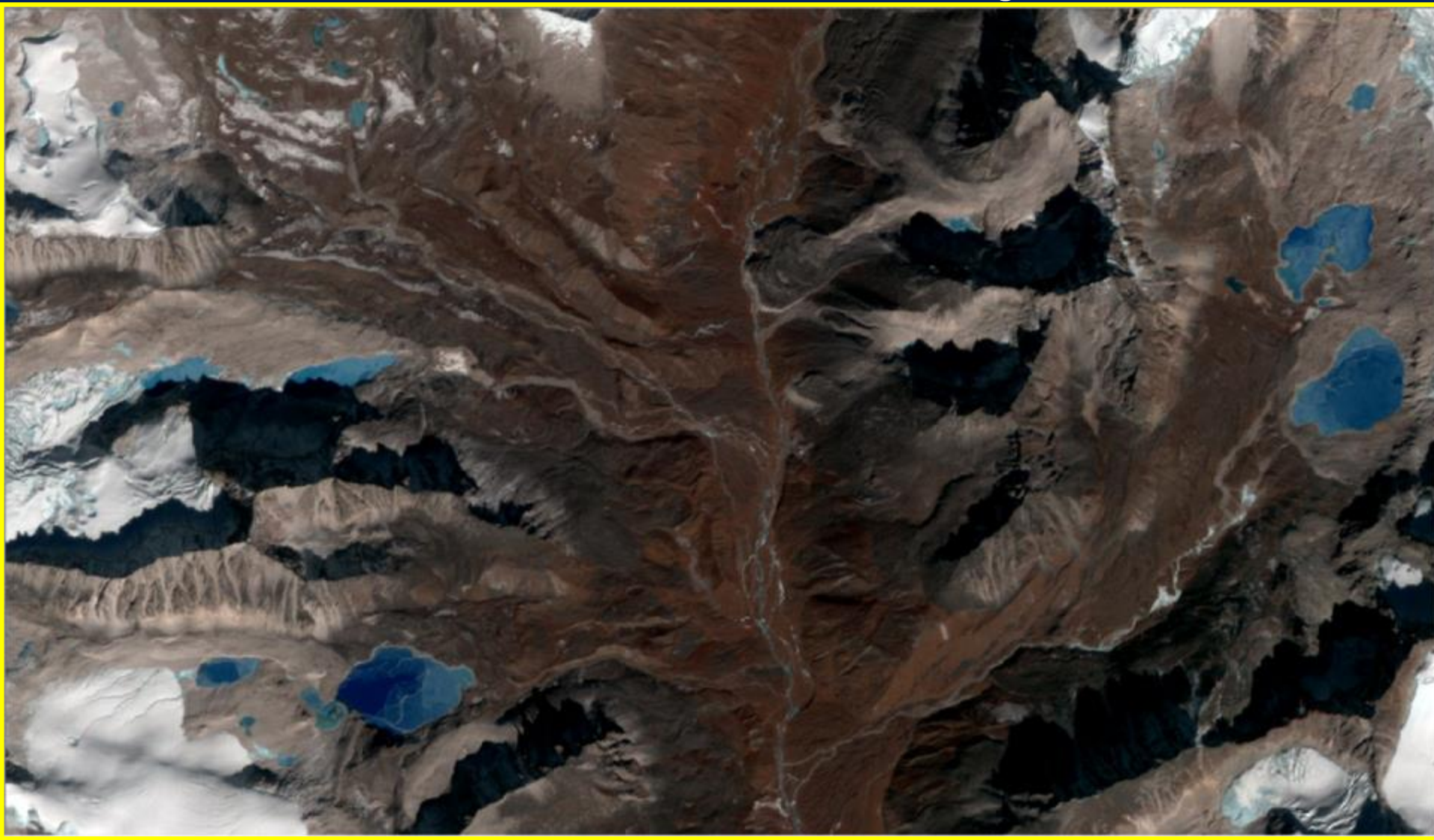


Spatial Resolution of 56 m

Glacier Lake Identification and Mapping Using RS Data

Inventory of Glacial Lakes

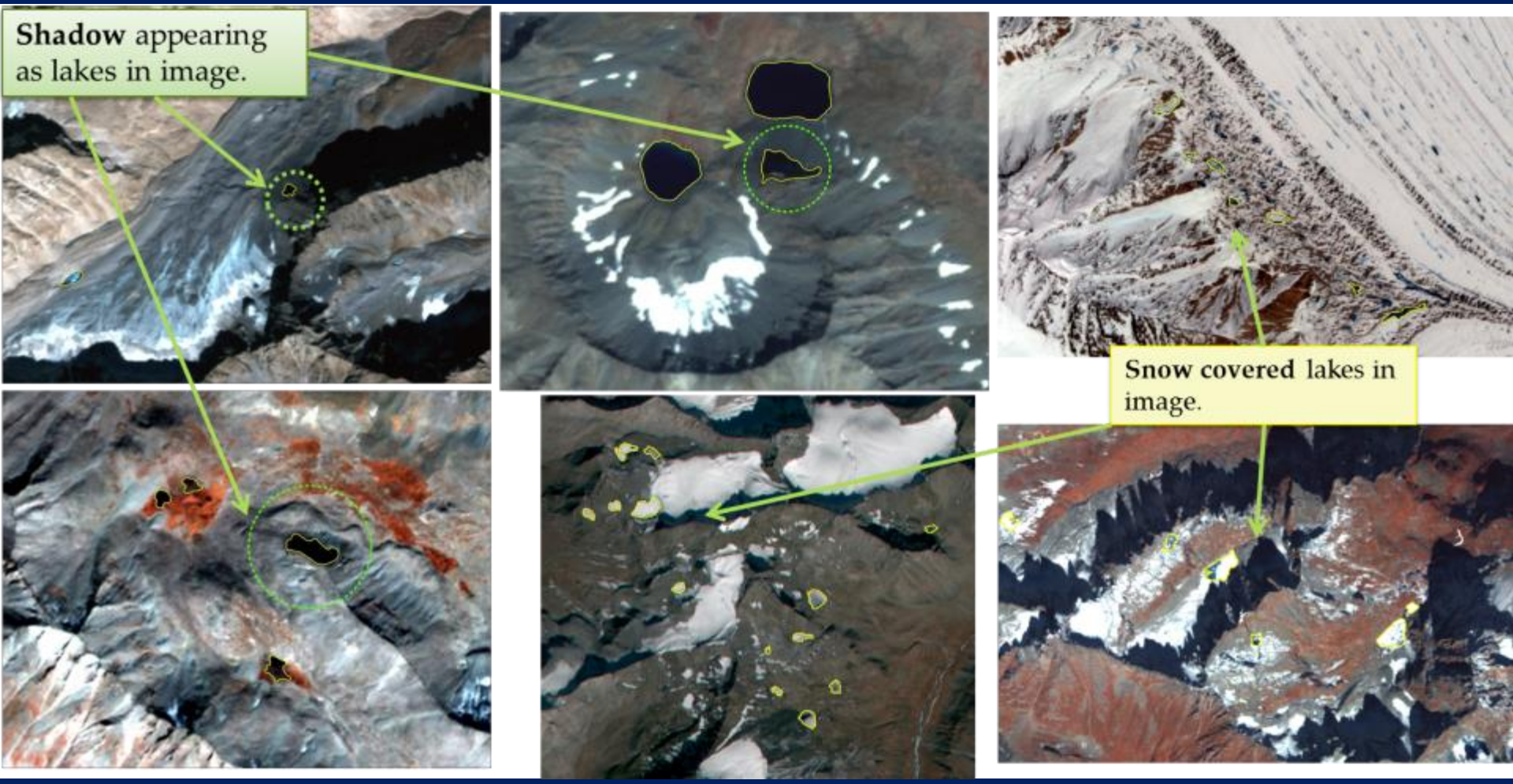
Glacial Lakes as seen on RS-2 LISS-IV satellite image of 16-Dec-2016



Spatial Resolution of 5.8 m

Glacier Lake Identification and Mapping Using RS Data

Difficulties in Satellite Interpretation



Glacier Lake Identification and Mapping Using RS Data

Difficulties in Satellite Interpretation

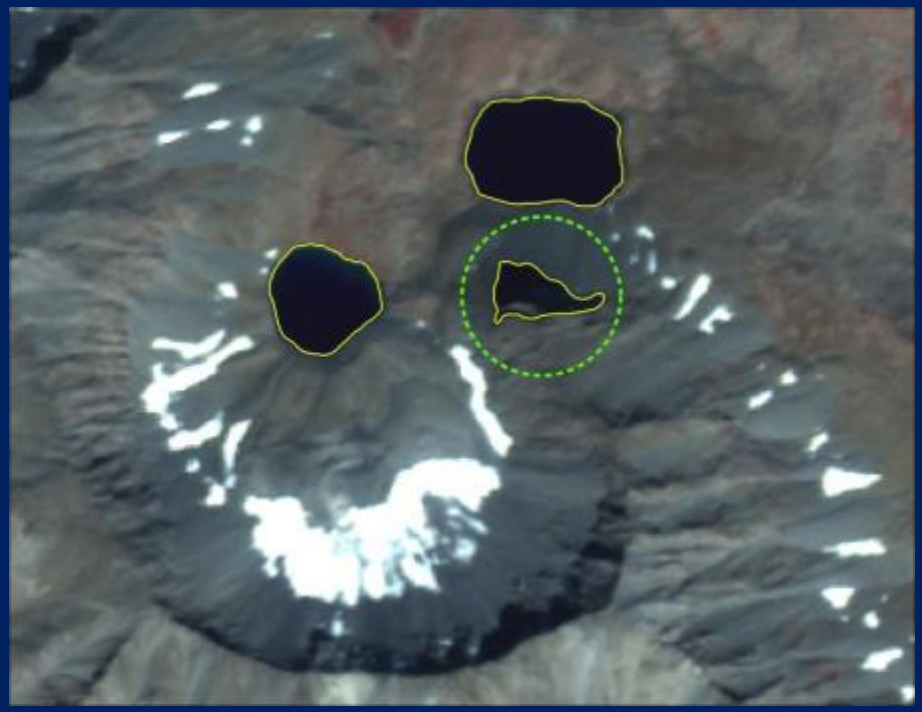
Glacier Lake Identification and Mapping Using RS Data

Difficulties in Satellite Interpretation

Glacier Lake Identification and Mapping Using RS Data

Difficulties in Satellite Interpretation

- Presence of snow or cloud over glacial lakes
- Glacial lakes under frozen condition
- Glacial lakes under mountain shadow

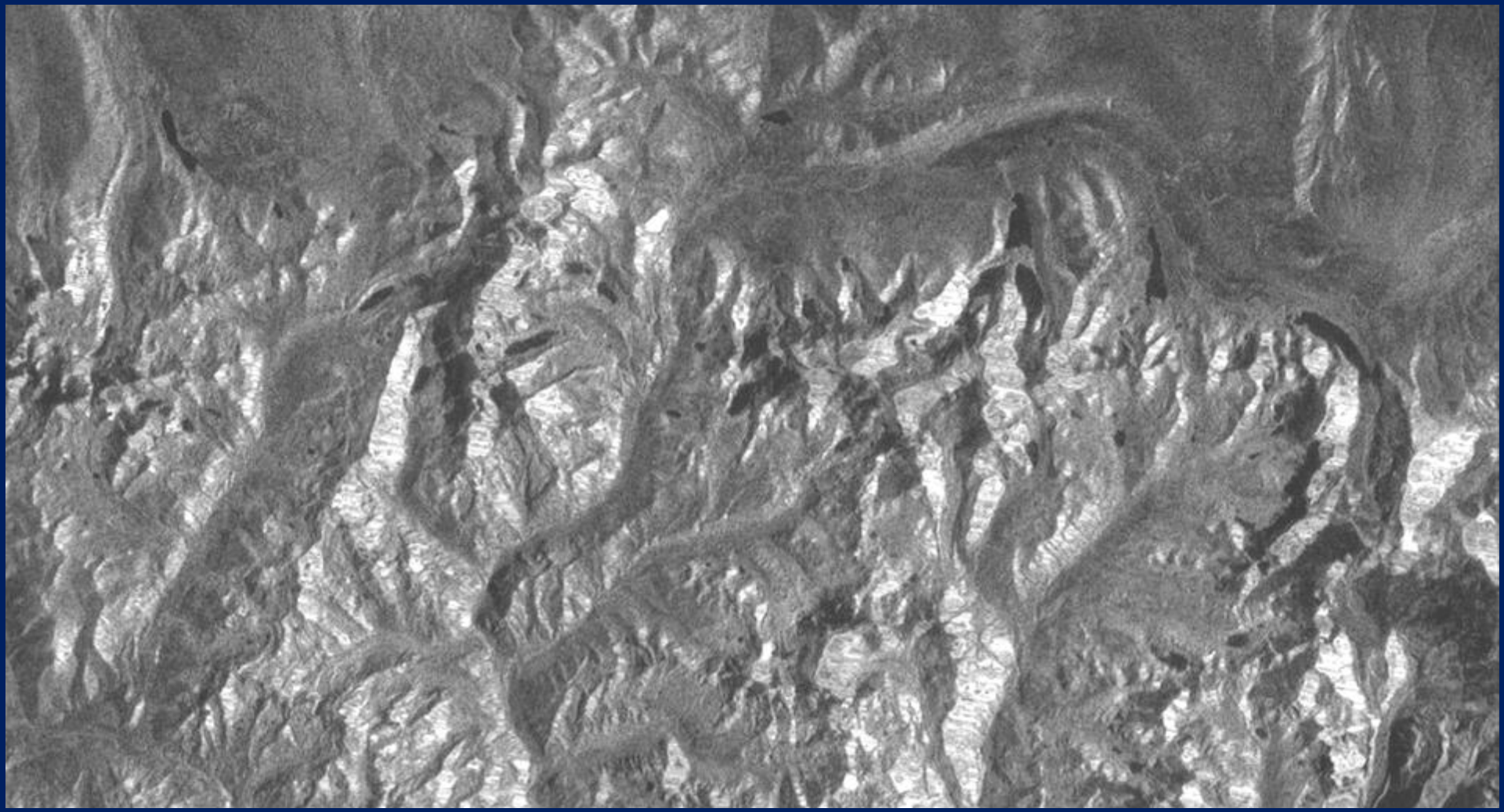


Feature Mapped using RS2-L4

Mountain shadow in Very High resolution image

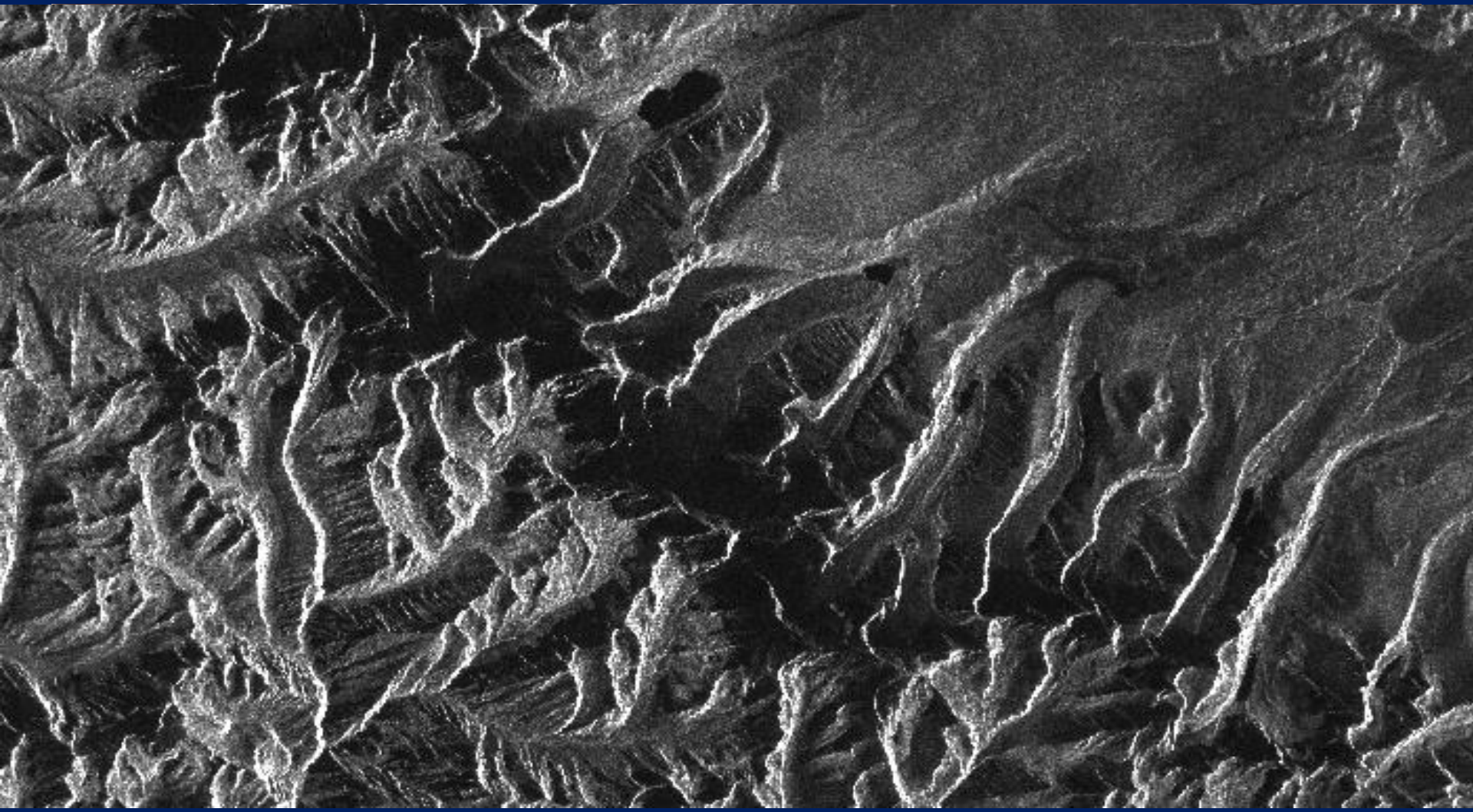
Glacier Lake Identification and Mapping Using

Microwave RS Data



Glacier Lake Identification and Mapping Using RS Data

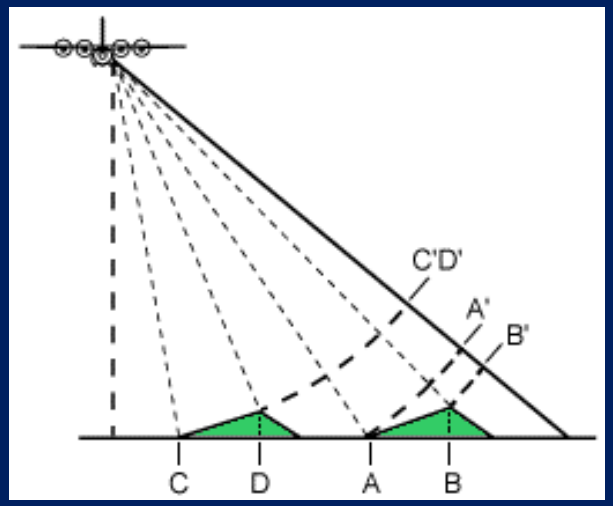
Glacial Lakes as seen on Optical and SAR Image



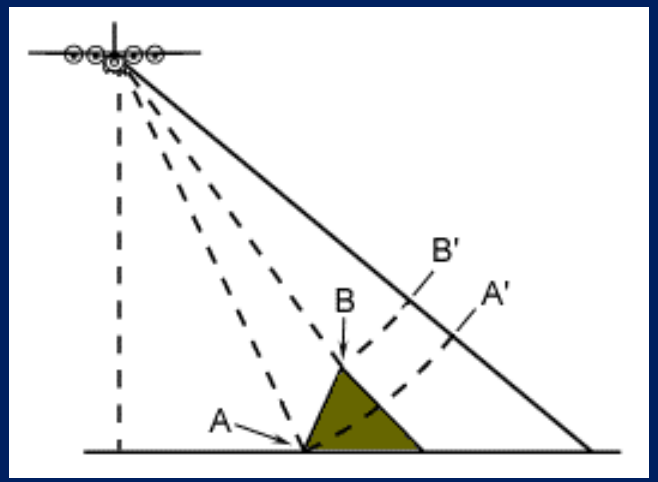
Brahmaputra basin (Nepal)

Geometric Effects in SAR

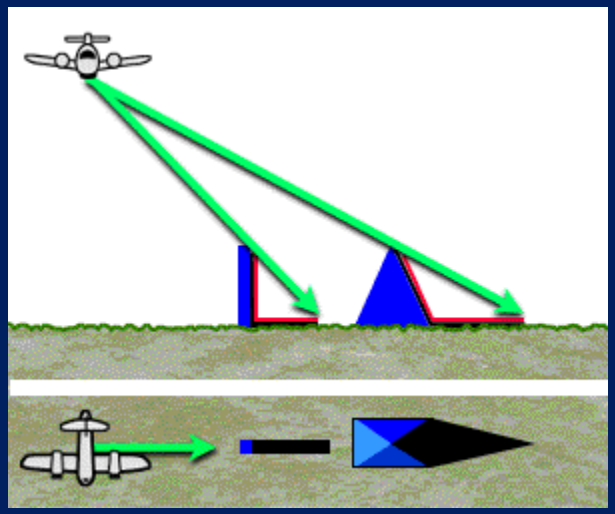
Foreshortening



Layover

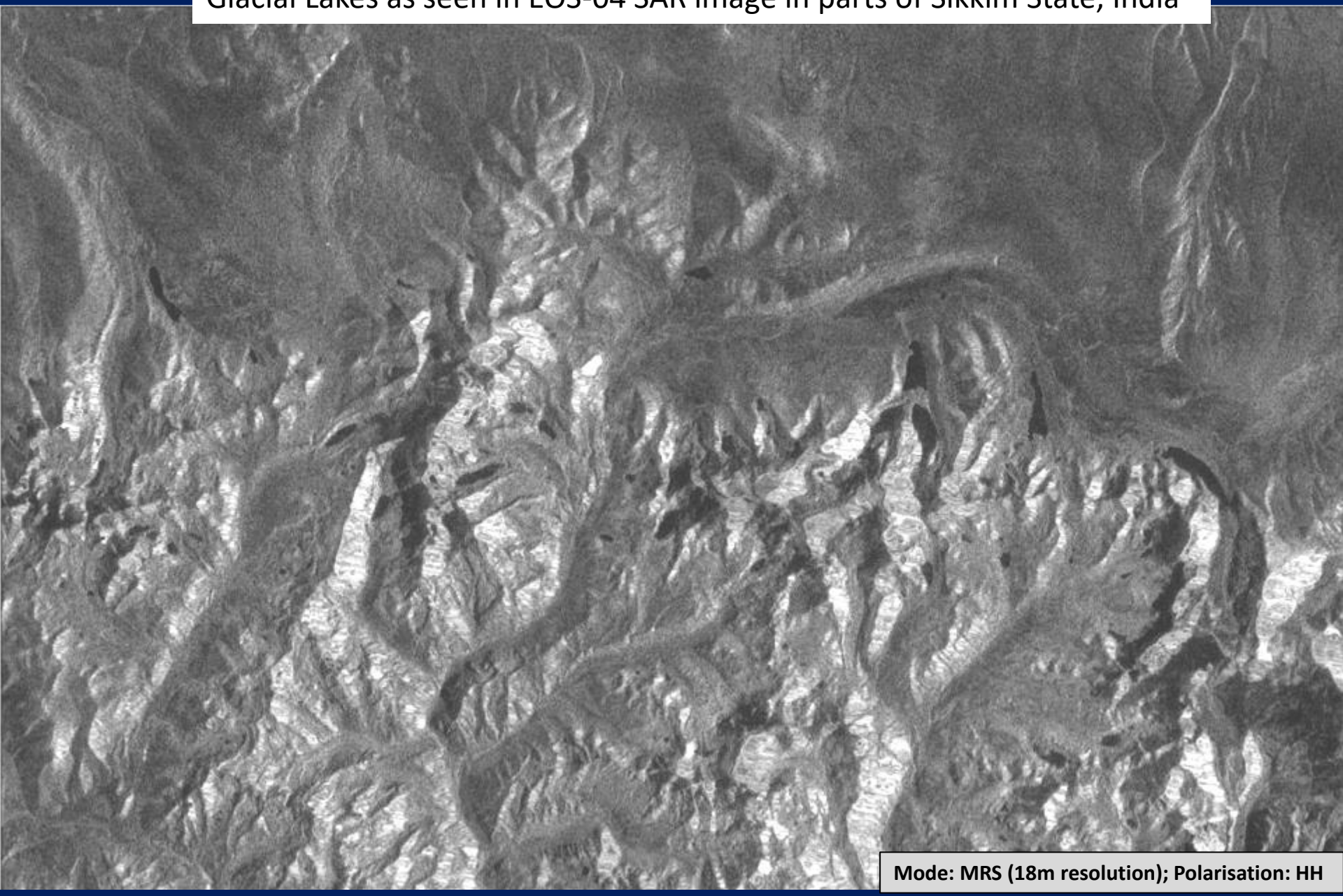


Shadows



Glacier Lake Identification and Mapping Using RS Data

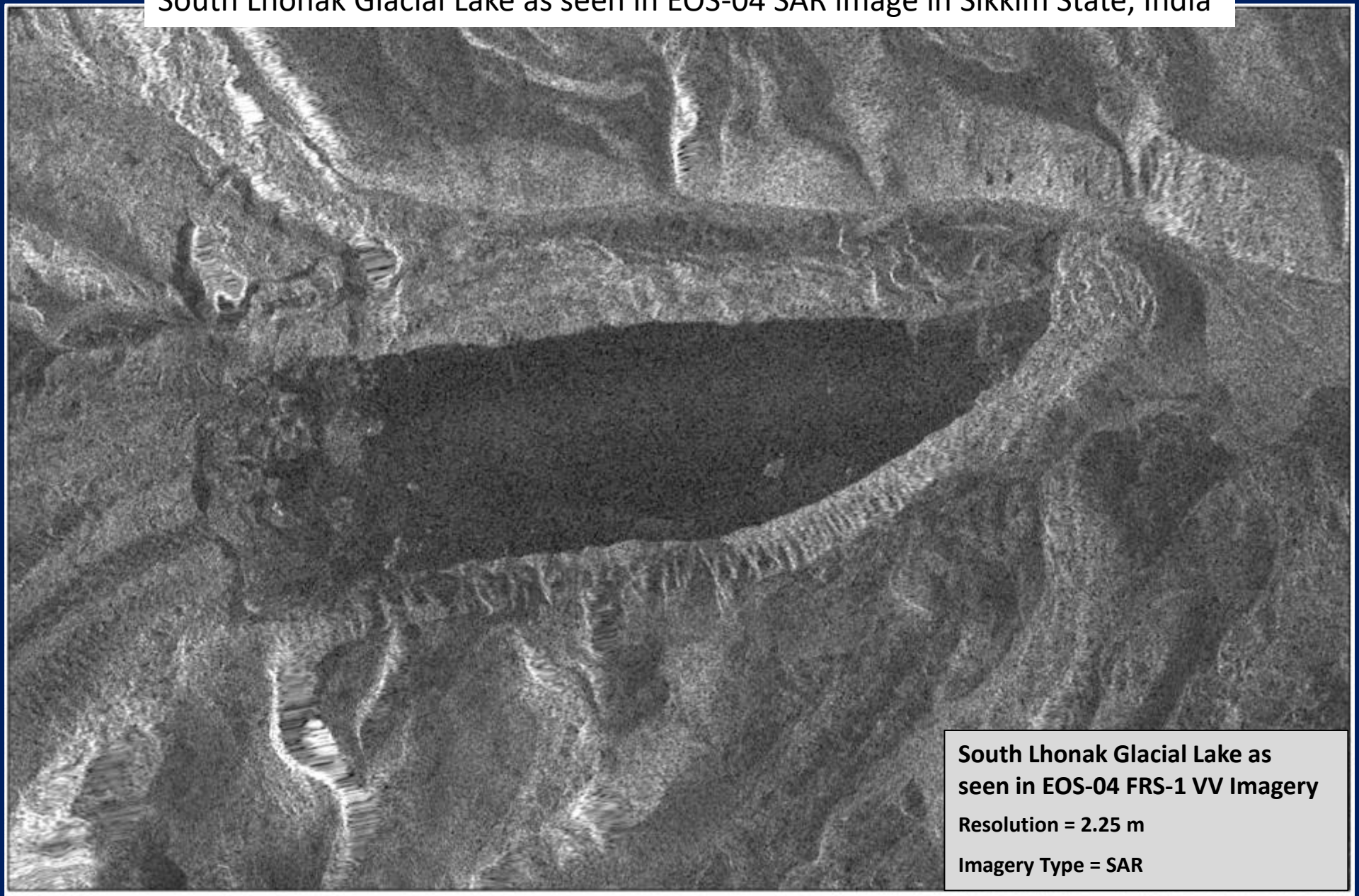
Glacial Lakes as seen in EOS-04 SAR image in parts of Sikkim State, India



Mode: MRS (18m resolution); Polarisation: HH

Glacier Lake Identification and Mapping Using RS Data

South Lhonak Glacial Lake as seen in EOS-04 SAR image in Sikkim State, India



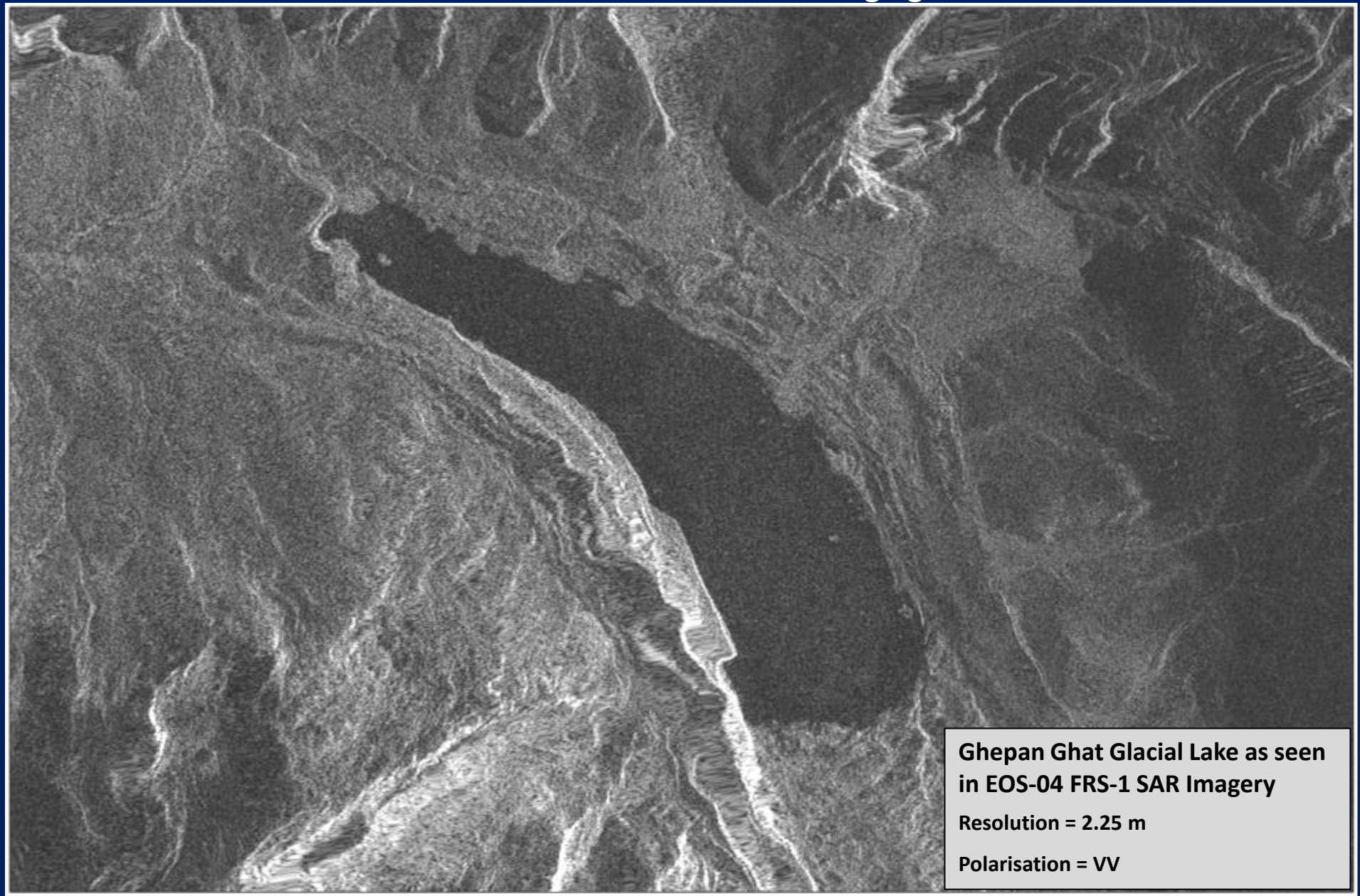
South Lhonak Glacial Lake as seen in EOS-04 FRS-1 VV Imagery

Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Different Polarisations of FRS-1 Imaging Mode



Ghepan Ghat Glacial Lake as seen in EOS-04 FRS-1 SAR Imagery

Resolution = 2.25 m

Polarisation = VV

Glacier Lake Identification and Mapping Using RS Data

South Lhonak Glacial Lake as seen on Optical and SAR Image

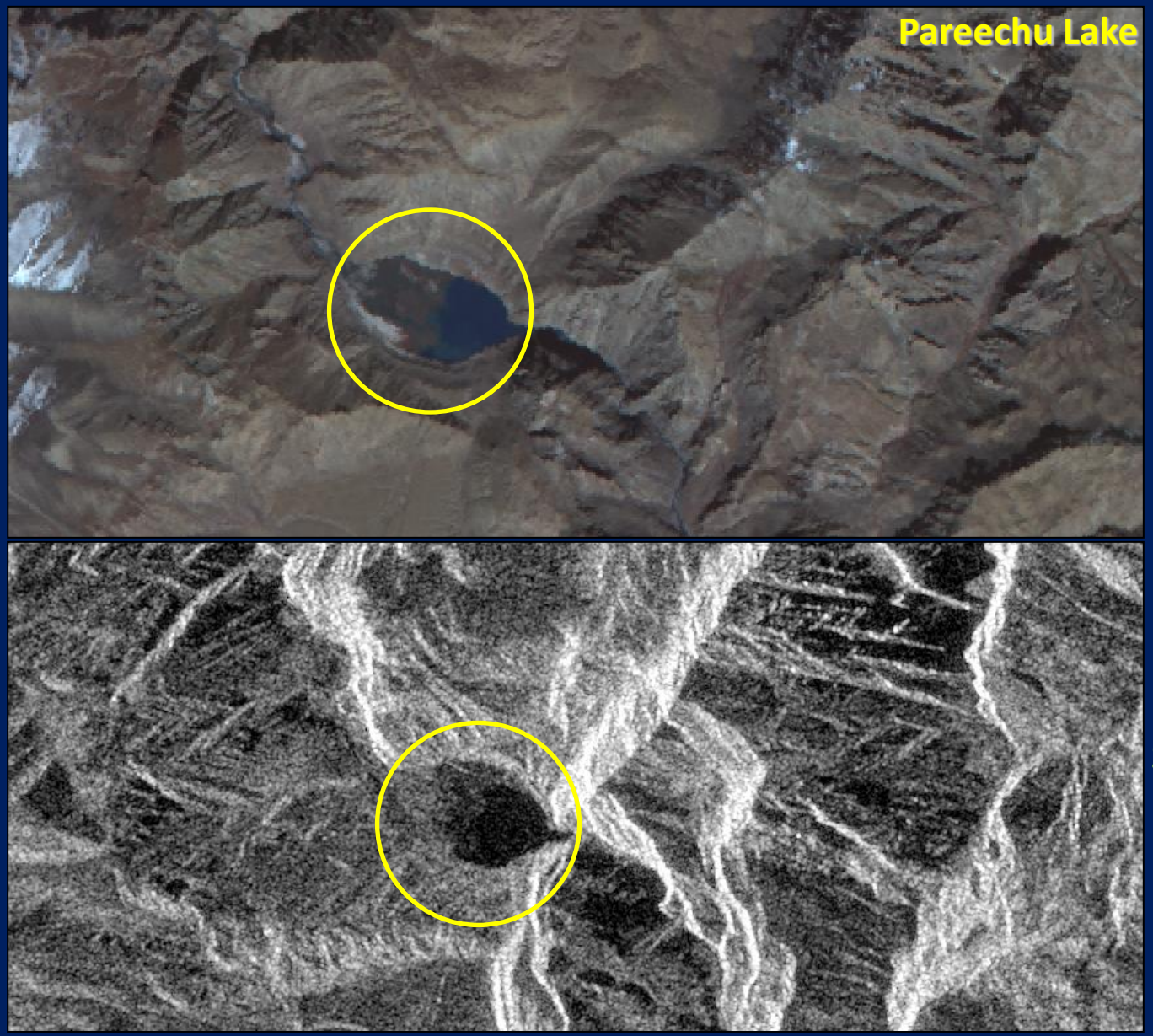
RS-2 LISS-IV MX FCC Image
Resolution = 5.8 m

EOS-04 FRS-1 VV Image
Resolution = 2.25 m

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Clear Sky Conditions

IRS-P6
LISS-III
Image of
23Oct2019



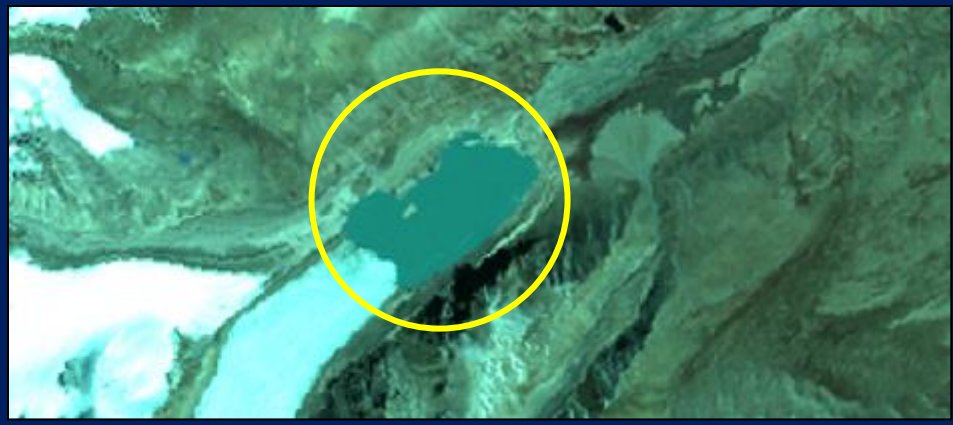
SAR Image
Polarisation:VV

Glacier Lake Identification and Mapping Using RS Data

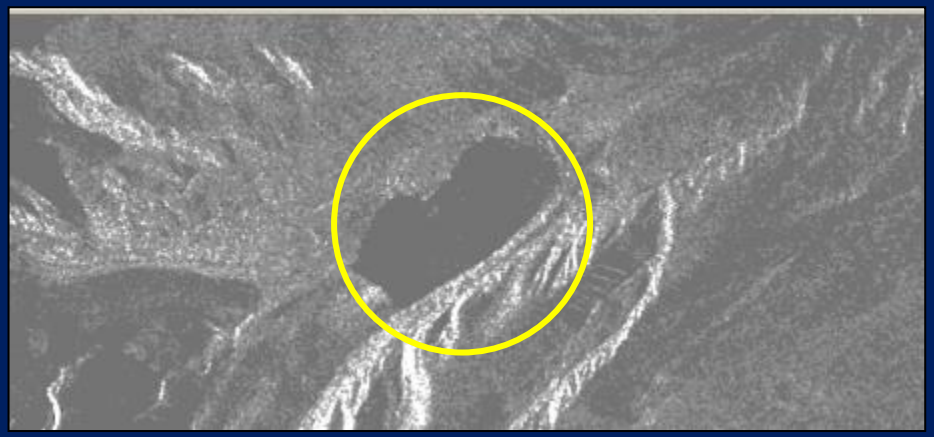
Glacial Lakes under Clear Sky Conditions

IRS-P6 LISS III – 10-July-2010

Landsat ETM - 2000

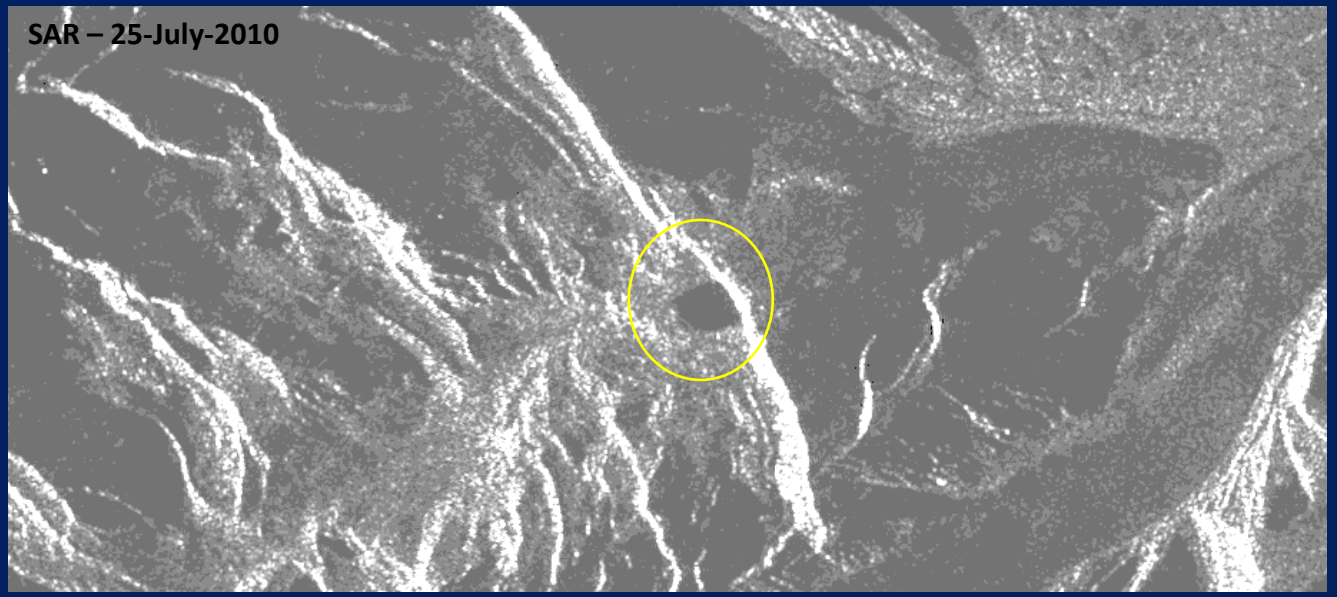


SAR – 25-July-2010



Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Fully Cloudy Conditions



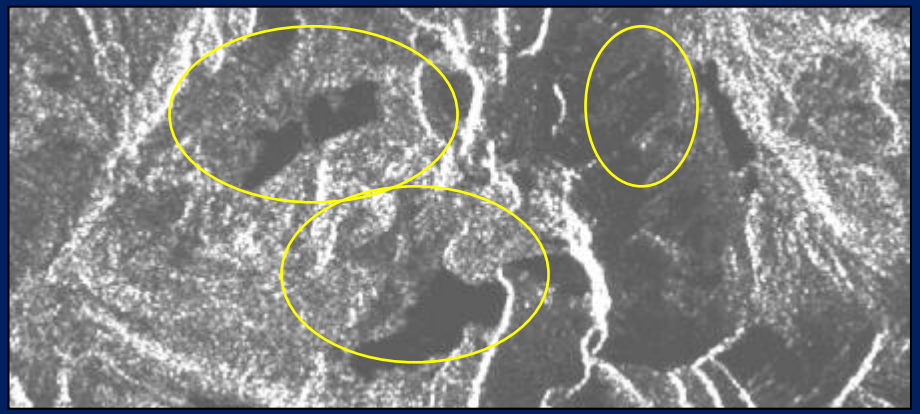
Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Fully & Partly Cloudy Conditions

IRS-P6 LISS III – 21-July-2010

Landsat ETM Image of 2010

ENVISAT ASAR – 26-July-2010

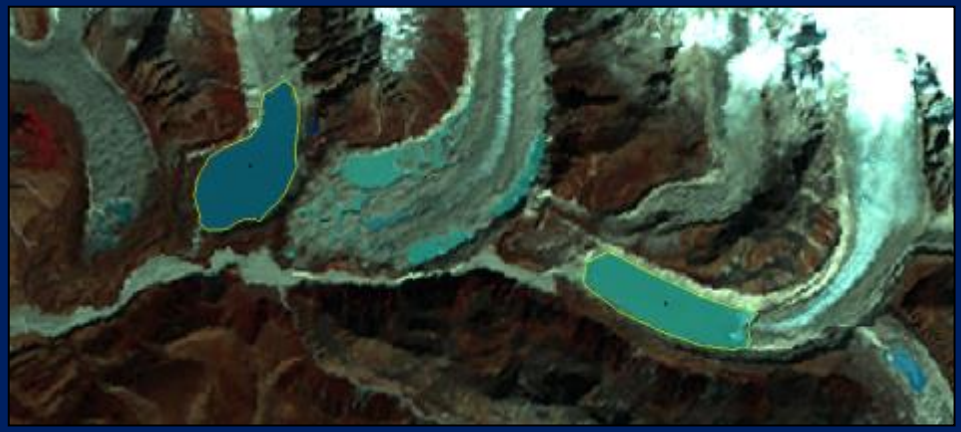


Glacier Lake Identification and Mapping Using RS Data

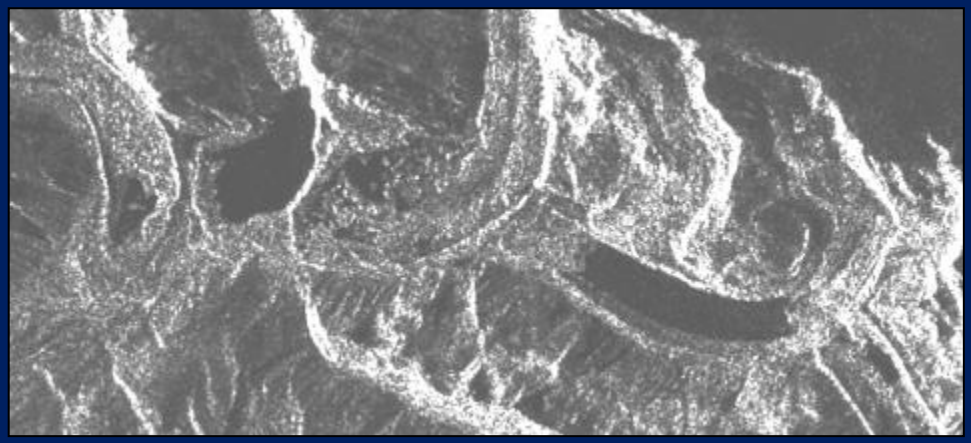
Glacial Lakes under Fully & Partly Cloudy Conditions

IRS-P6 LISS III – 21-July-2010

Landsat ETM Image of 2010



SAR Image of 26-July-2010

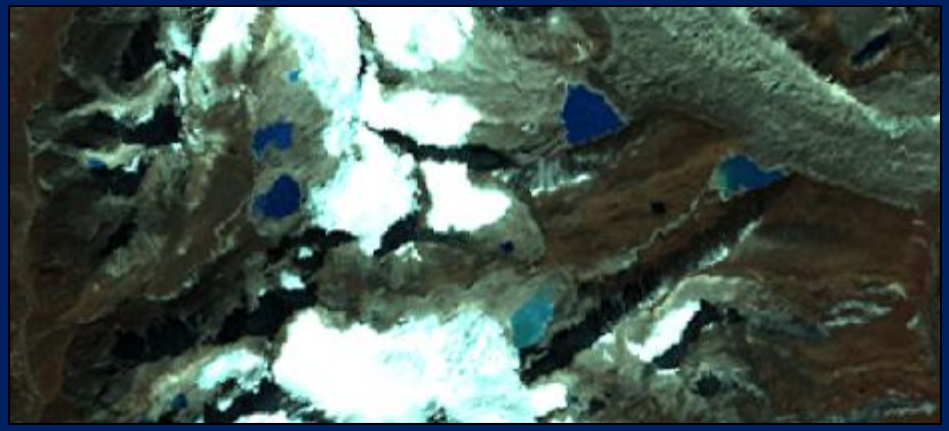


Glacier Lake Identification and Mapping Using RS Data

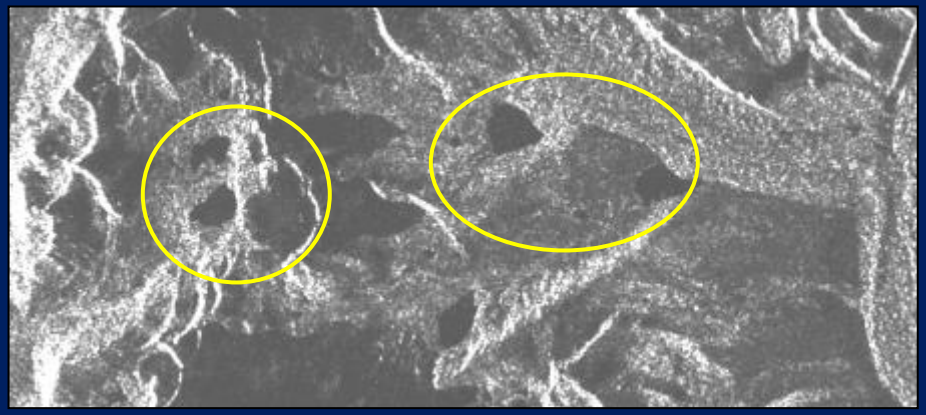
Glacial Lakes under Fully & Partly Cloudy Conditions

IRS-P6 LISS III – 21-July-2010

Landsat ETM Image of 2010

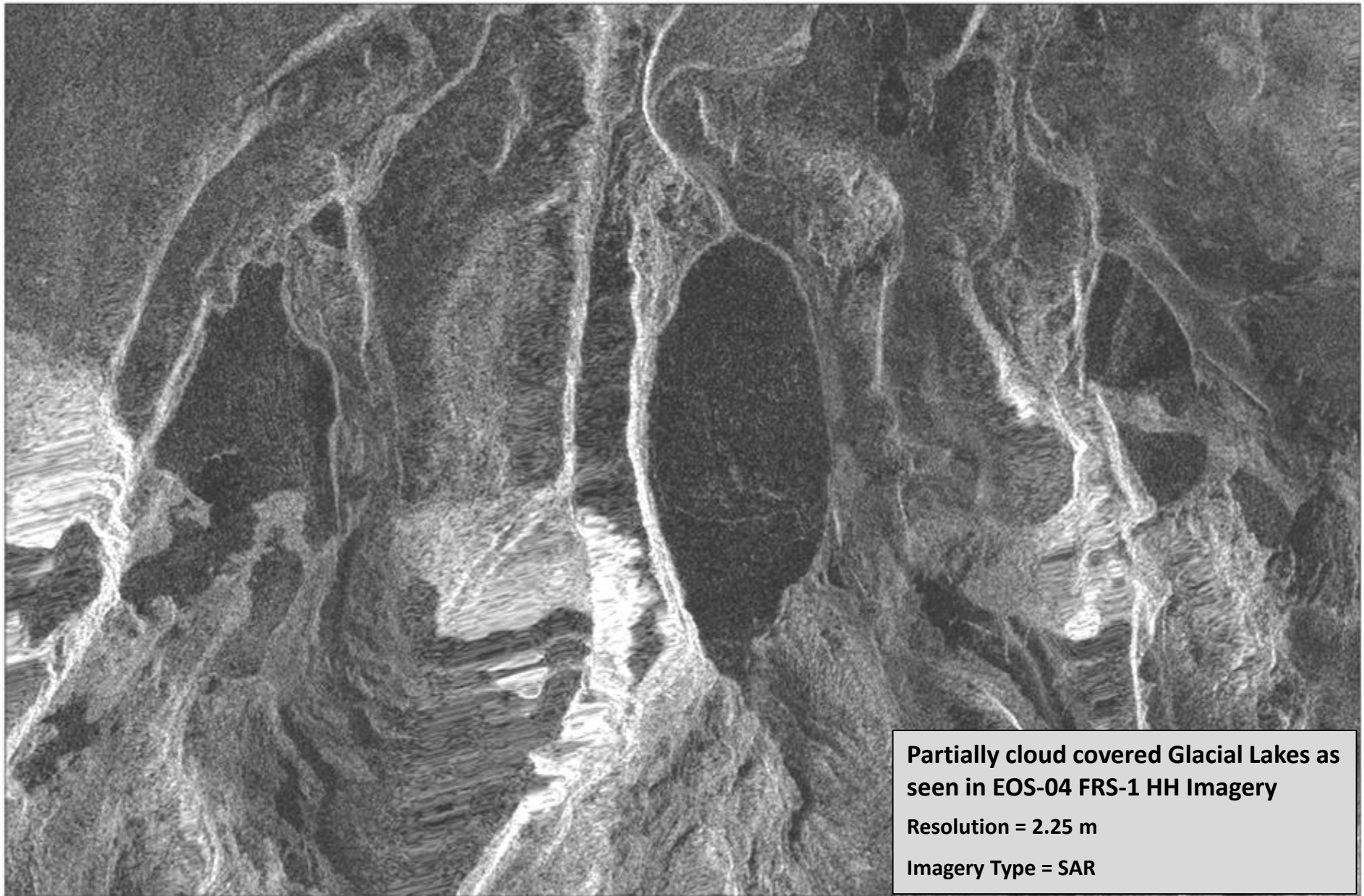


SAR Image of 26-July-2010



Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Fully & Partly Cloudy Conditions



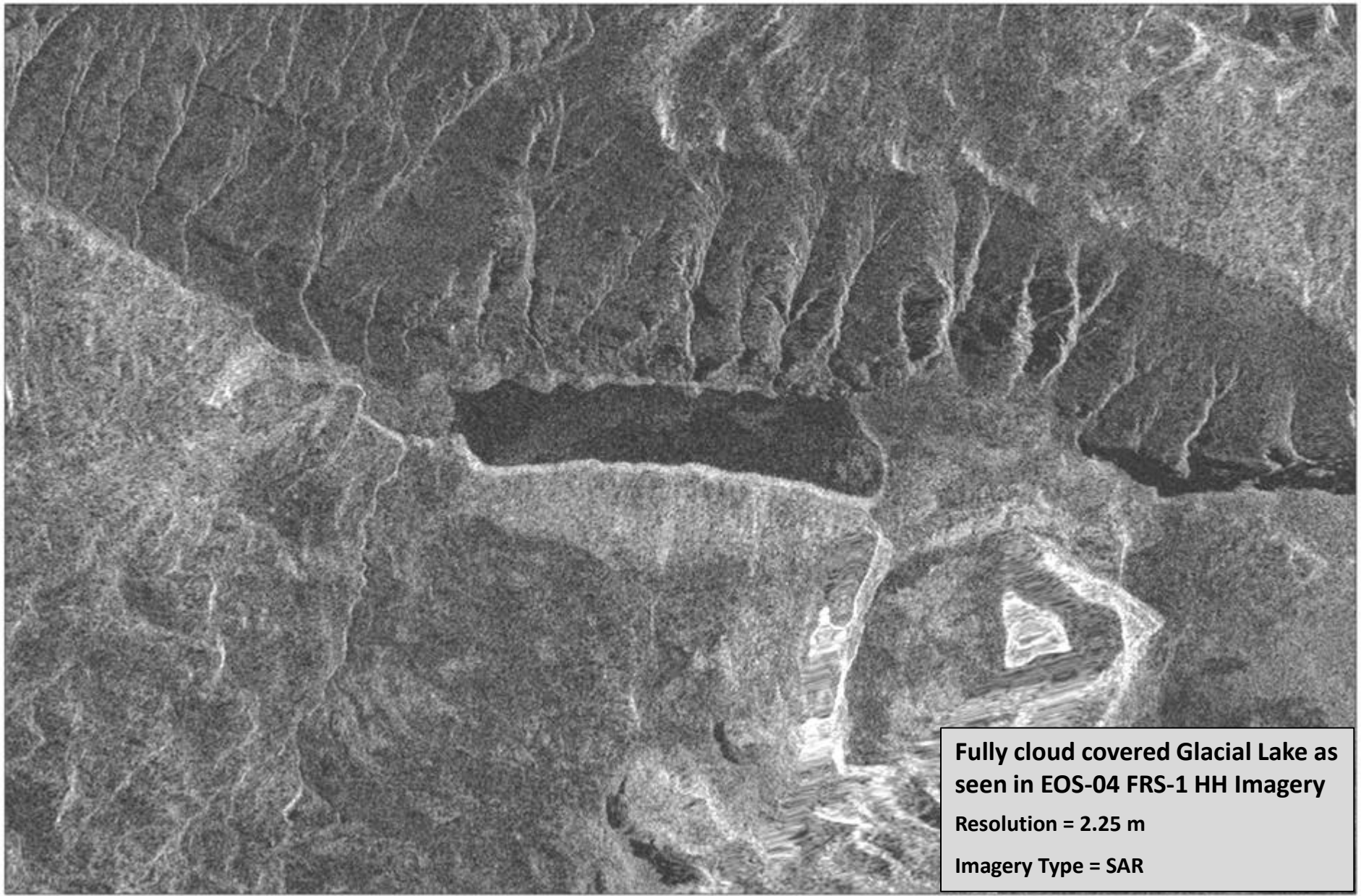
Partially cloud covered Glacial Lakes as seen in EOS-04 FRS-1 HH Imagery

Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Fully & Partly Cloudy Conditions



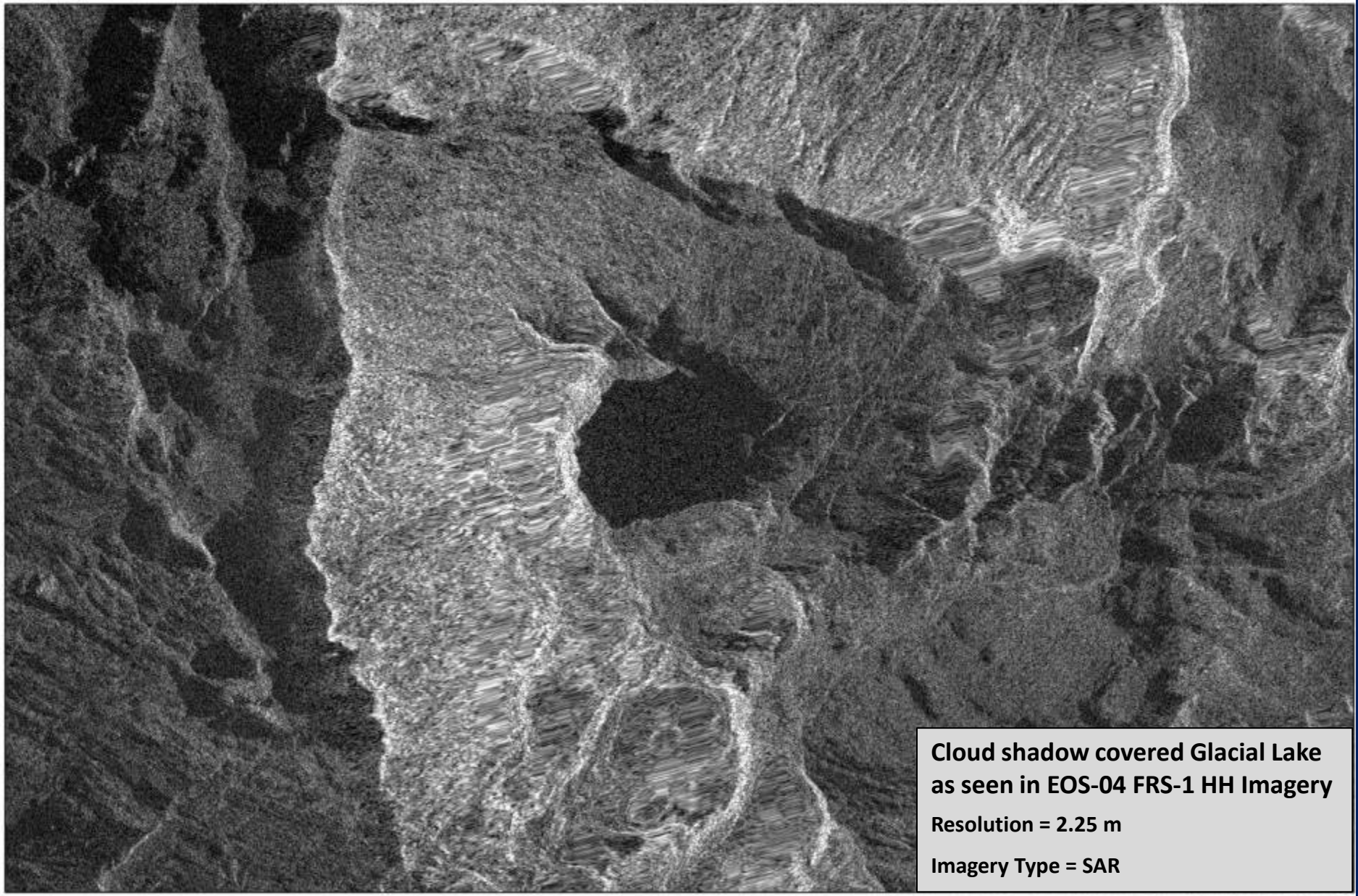
Fully cloud covered Glacial Lake as seen in EOS-04 FRS-1 HH Imagery

Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Fully & Partly Cloudy Conditions



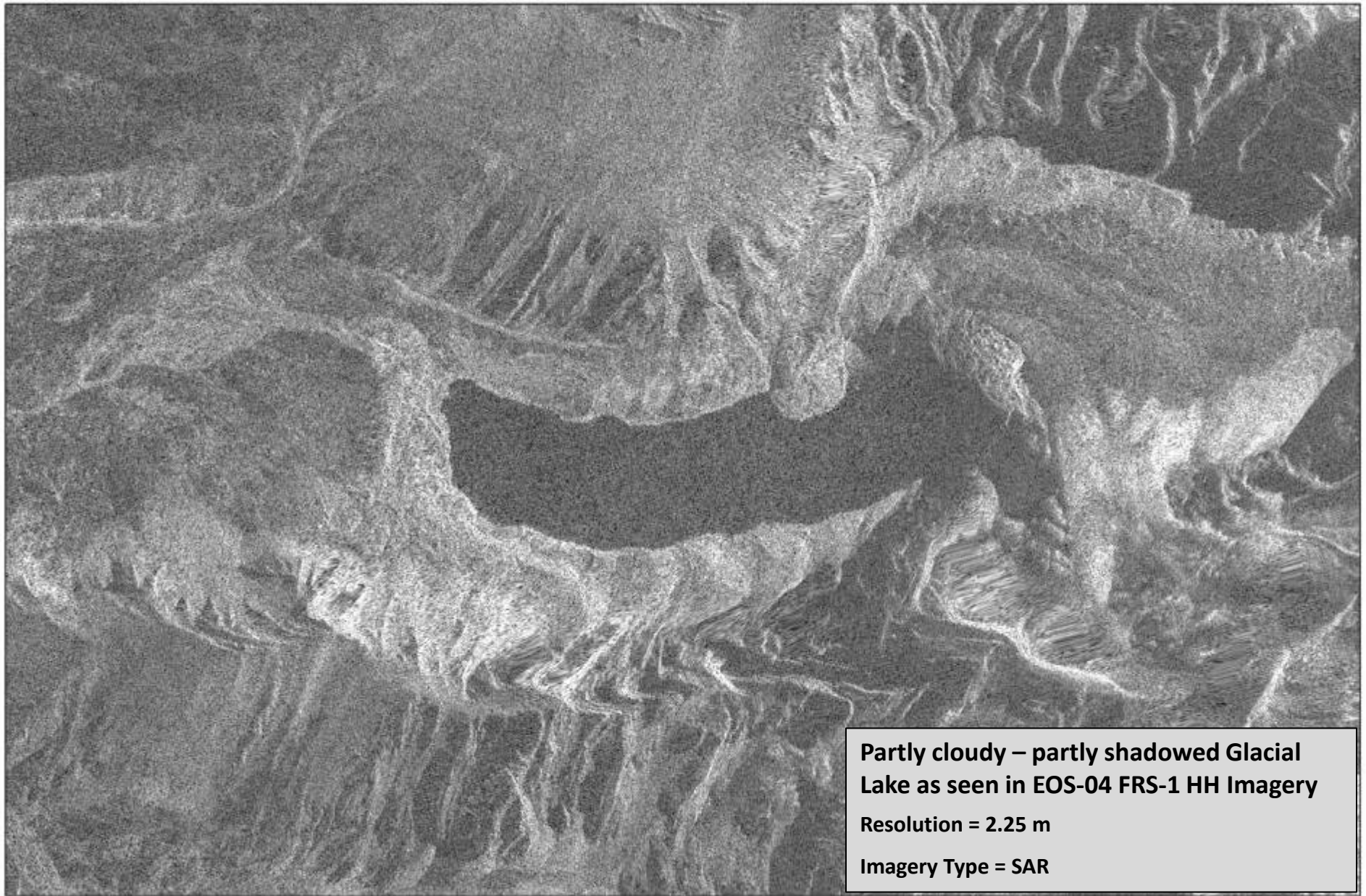
Cloud shadow covered Glacial Lake as seen in EOS-04 FRS-1 HH Imagery

Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Fully & Partly Cloudy Conditions



Partly cloudy – partly shadowed Glacial Lake as seen in EOS-04 FRS-1 HH Imagery

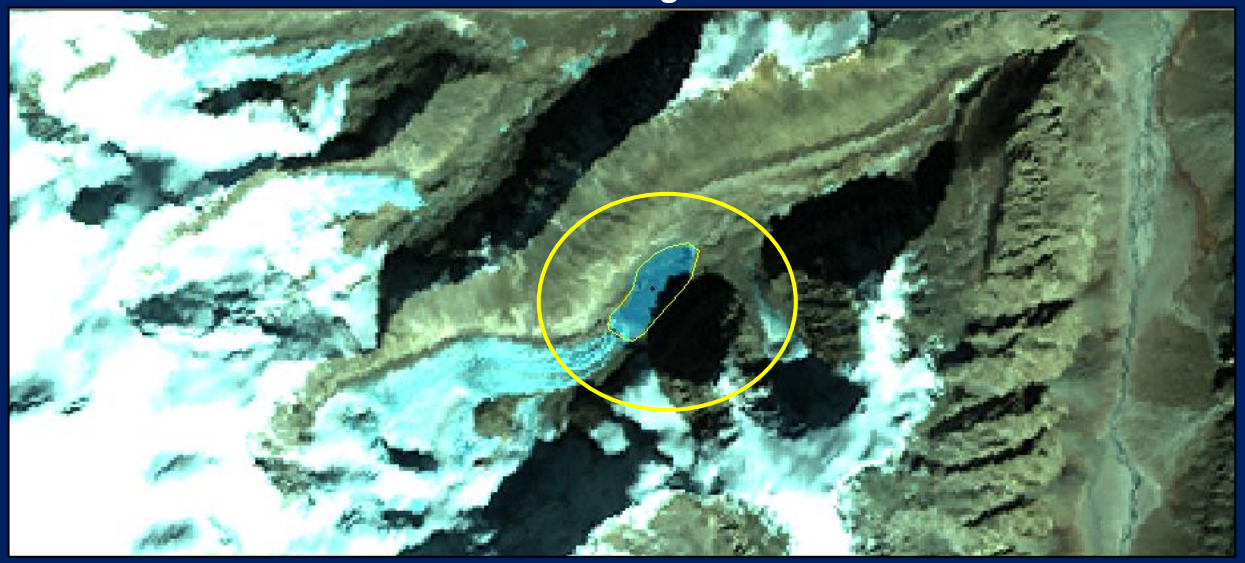
Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Partly Mountain Shadow

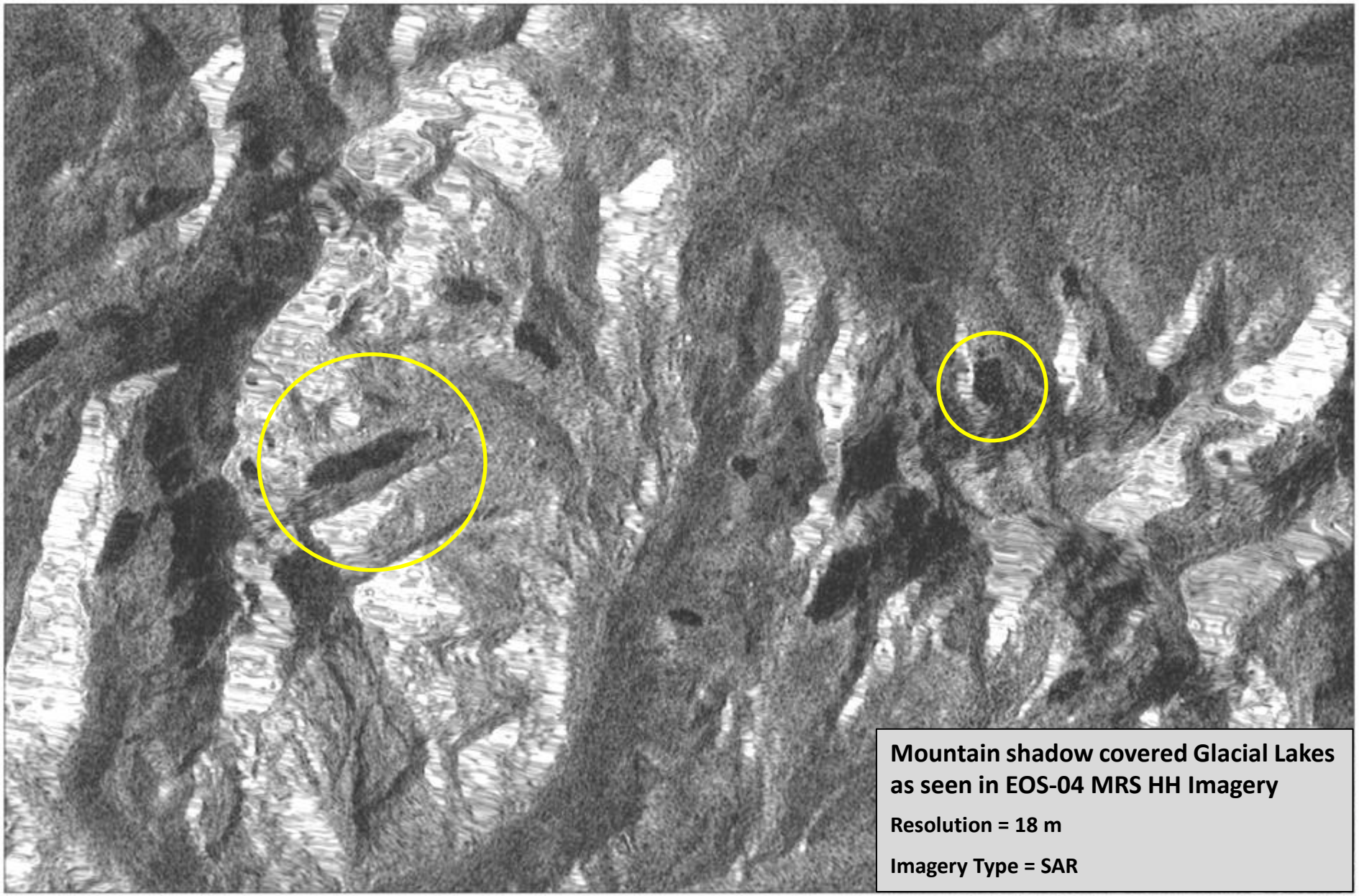
Landsat ETM Image of 2010



SAR Image of 26-July-2010

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Partly Mountain Shadow



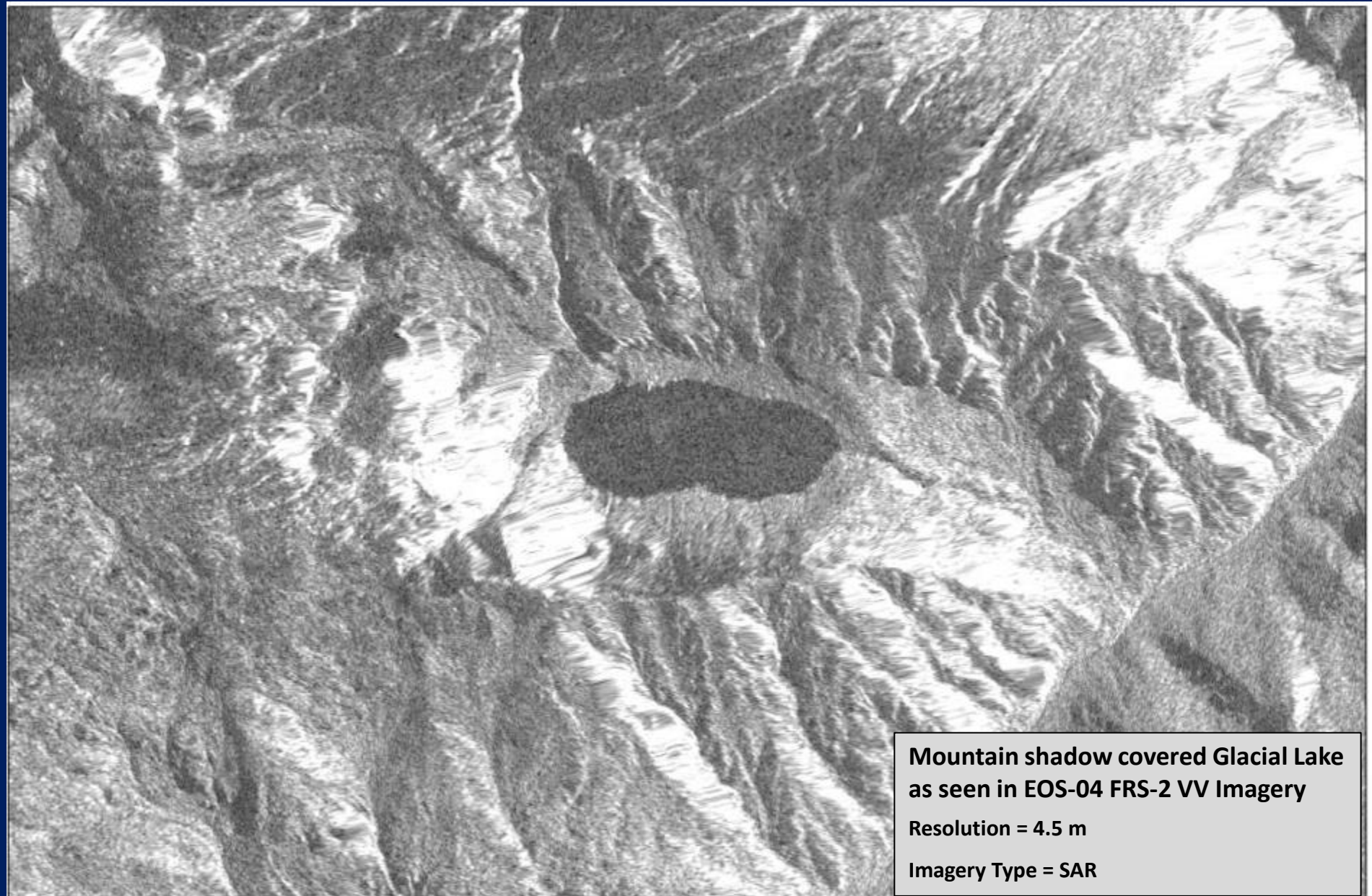
Mountain shadow covered Glacial Lakes as seen in EOS-04 MRS HH Imagery

Resolution = 18 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Partly Mountain Shadow



Mountain shadow covered Glacial Lake as seen in EOS-04 FRS-2 VV Imagery

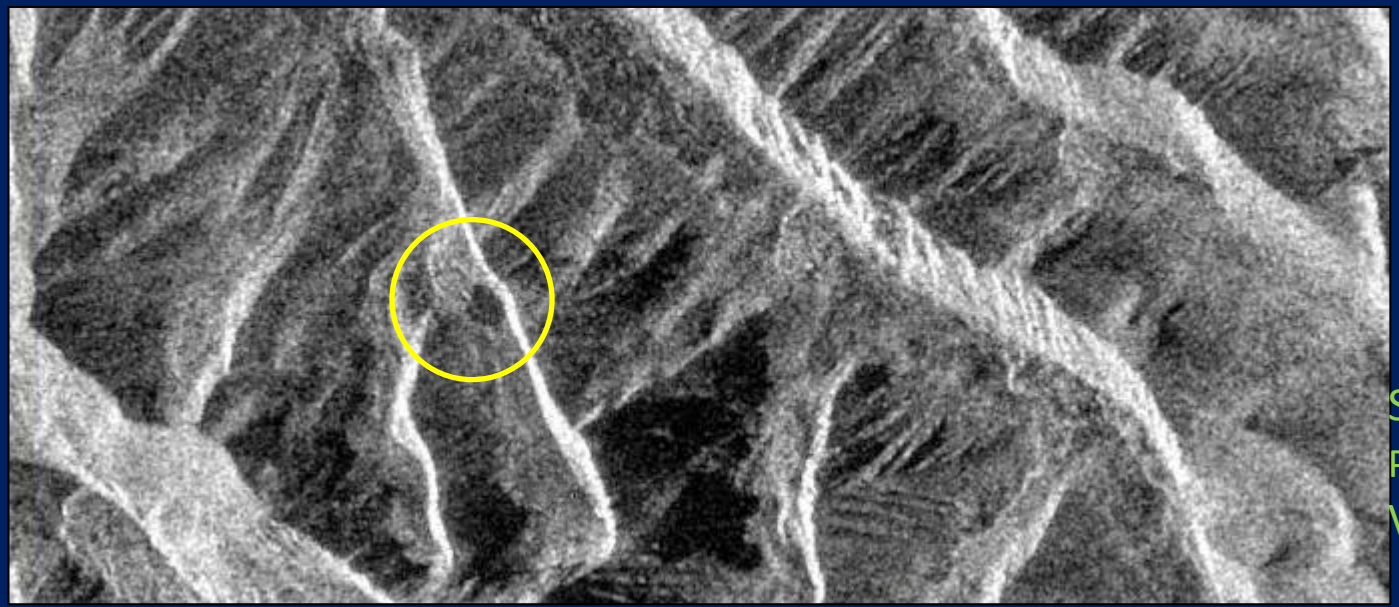
Resolution = 4.5 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Frozen Conditions

IRS-P6
LISS-III
Image of
23Oct2019

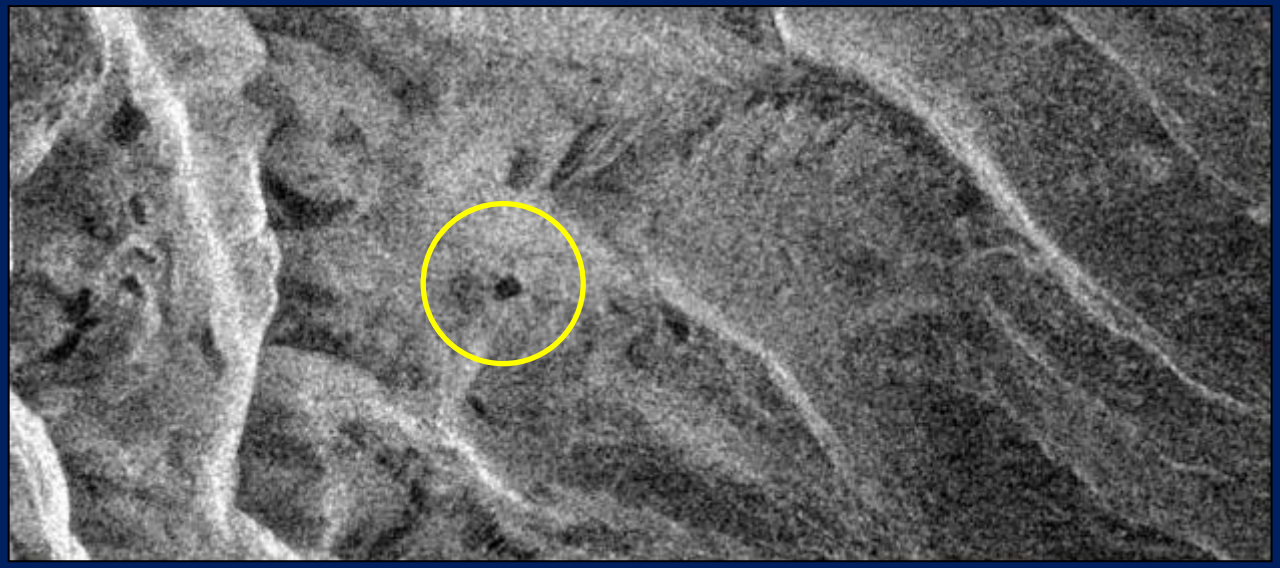


SAR Image
Polarisation:
VV

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Frozen Conditions

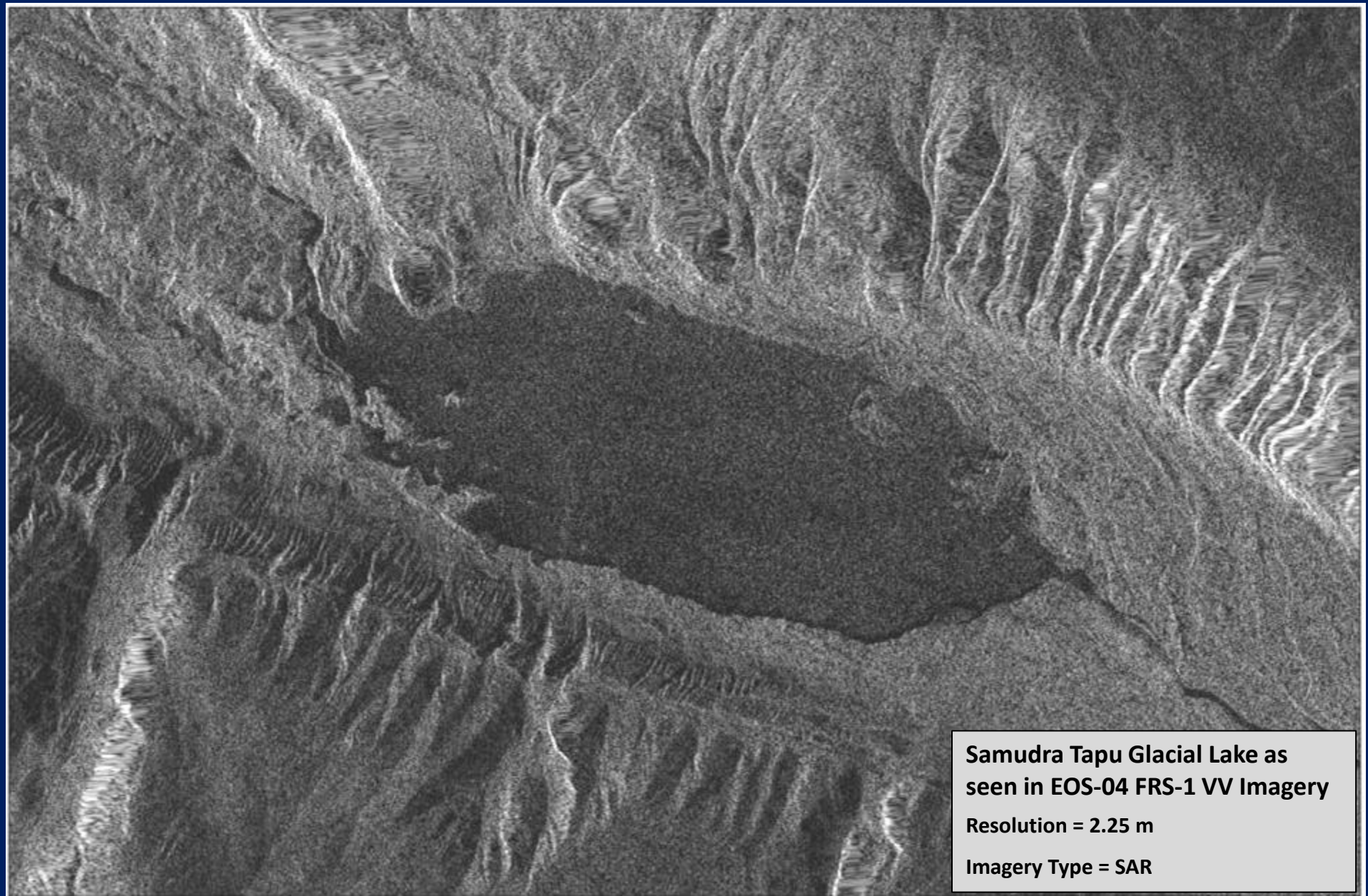
IRS-P6
LISS-III
Image of
23Oct2019



SAR Image
Polarisation:VV

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Frozen Conditions



Samudra Tapu Glacial Lake as seen in EOS-04 FRS-1 VV Imagery

Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Frozen Conditions

Ice covered Glacial Lakes as seen in EOS-04 FRS-2 VV Imagery

Resolution = 4.5 m

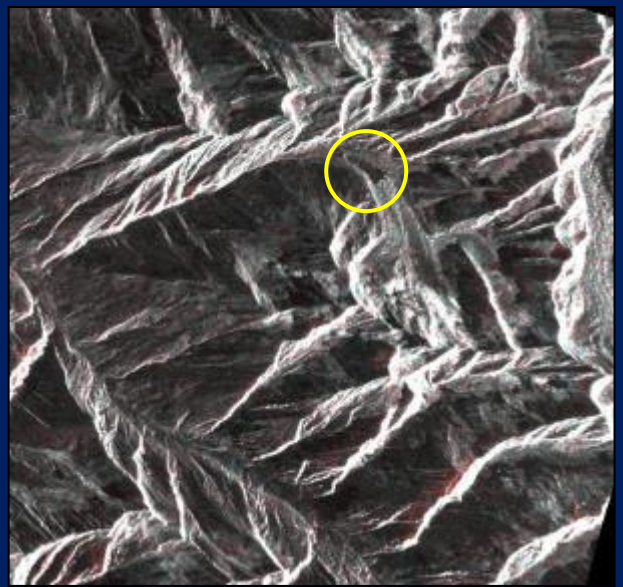
Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Glacial Lakes under Snow Cover

AWiFS data of 07 Sep 2004

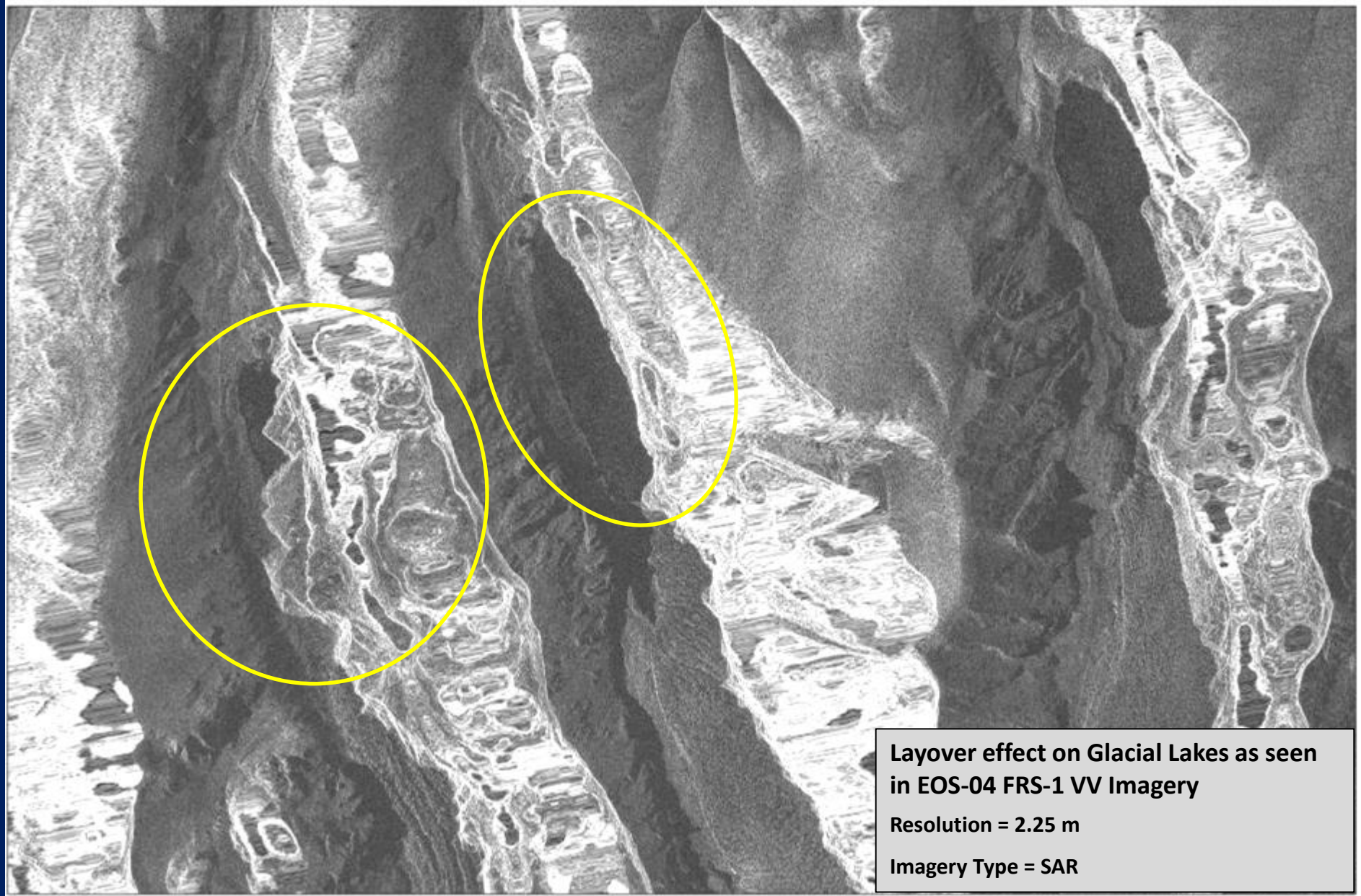
AWiFS data of 17 Feb 2006



SAR data of 24 Feb 2006

Glacier Lake Identification and Mapping Using RS Data

Problems in Glacial Lake Identification with SAR data



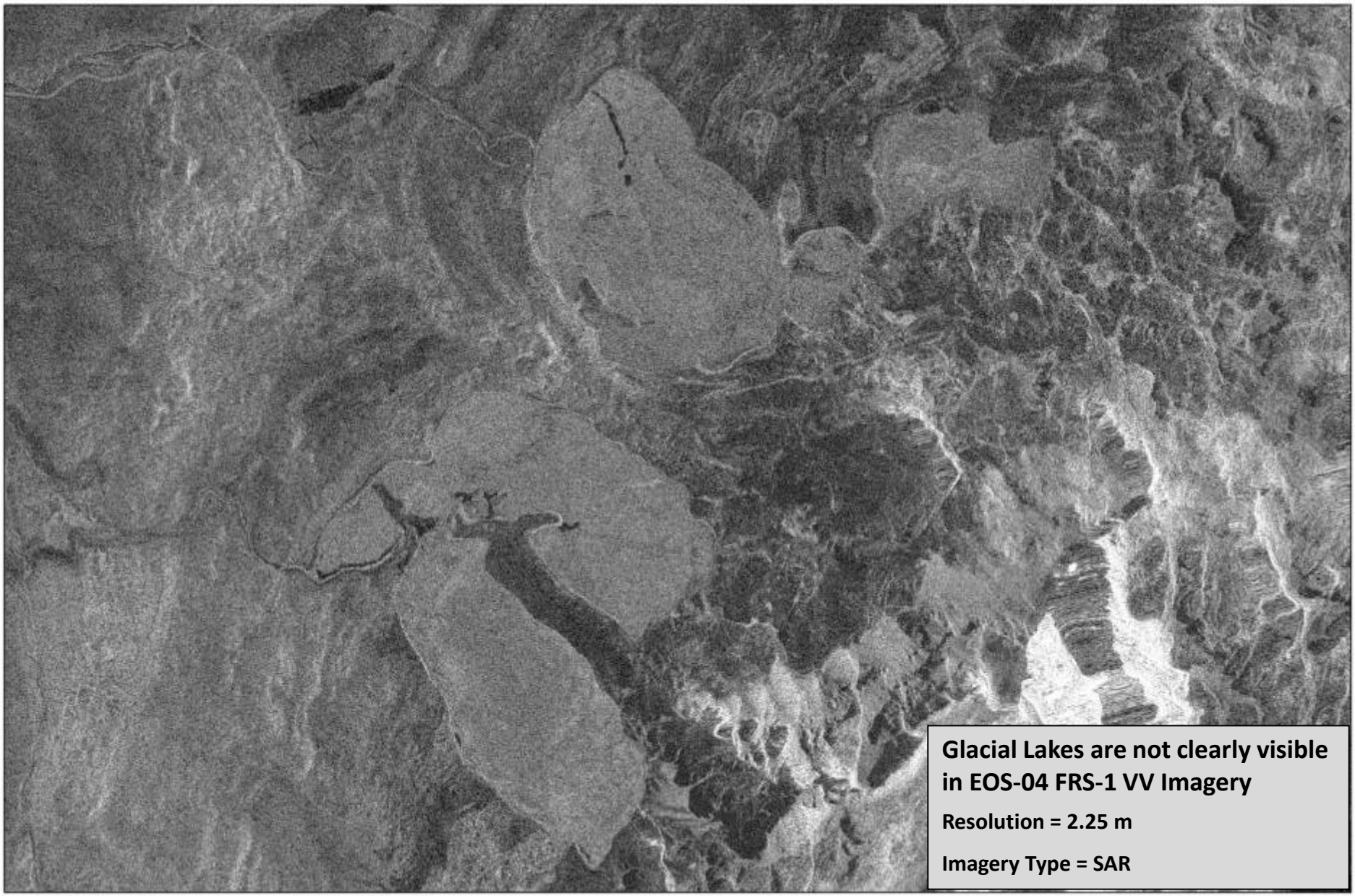
Layover effect on Glacial Lakes as seen in EOS-04 FRS-1 VV Imagery

Resolution = 2.25 m

Imagery Type = SAR

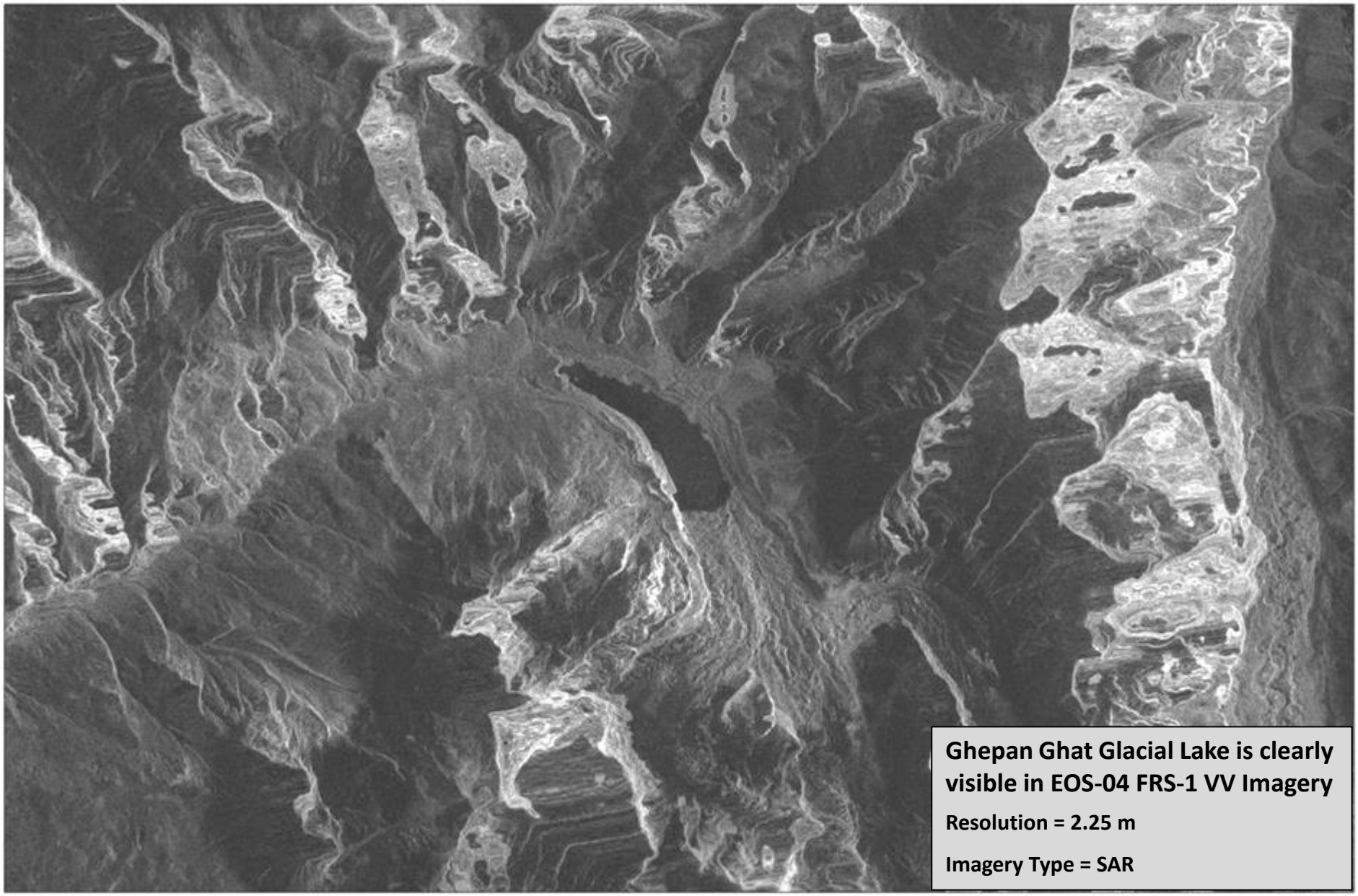
Glacier Lake Identification and Mapping Using RS Data

Problems in Glacial Lake Identification with SAR data



Glacier Lake Identification and Mapping Using RS Data

Problems in Glacial Lake Identification with SAR data



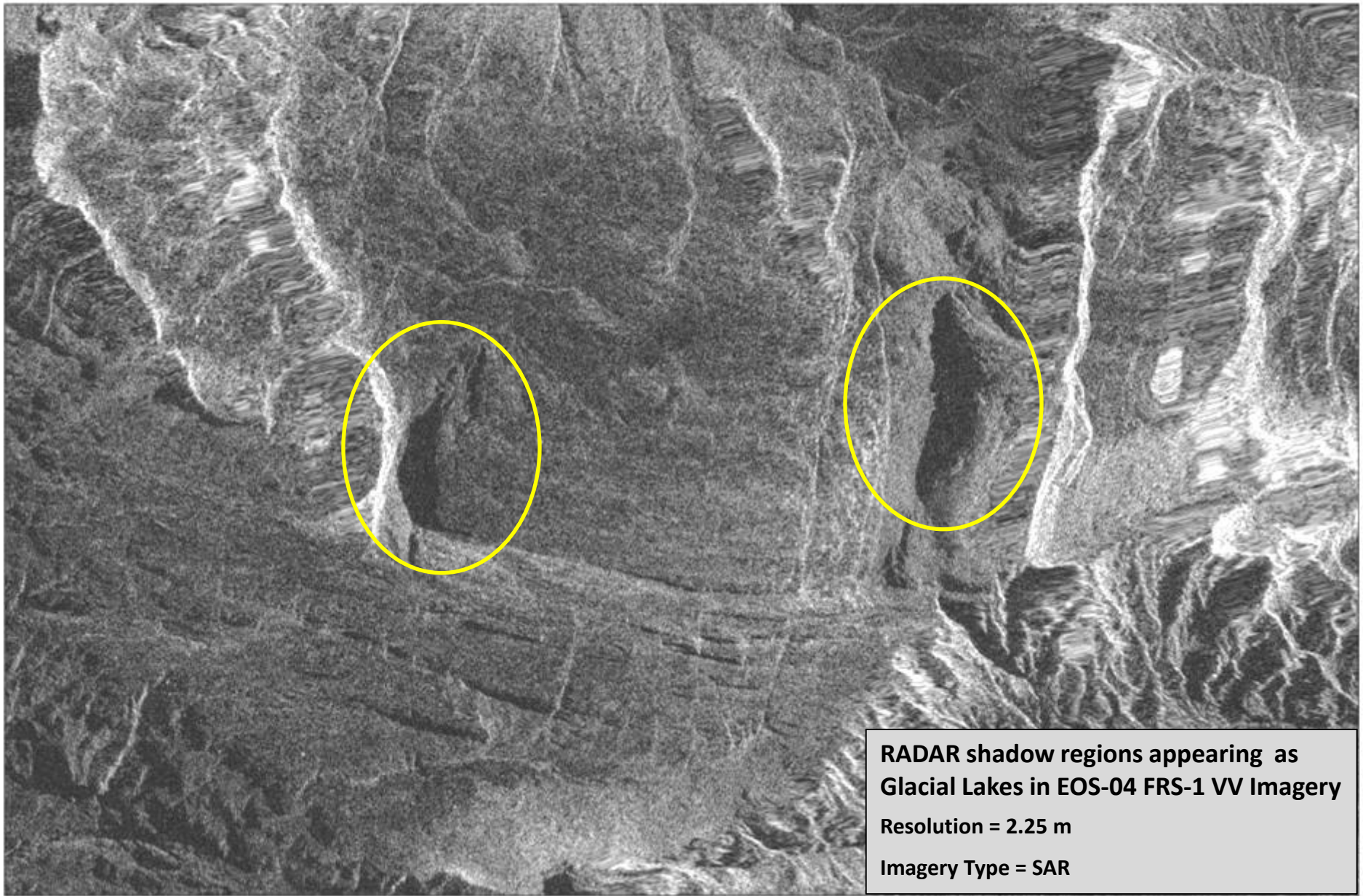
Ghepan Ghat Glacial Lake is clearly visible in EOS-04 FRS-1 VV Imagery

Resolution = 2.25 m

Imagery Type = SAR

Glacier Lake Identification and Mapping Using RS Data

Problems in Glacial Lake Identification with SAR data



RADAR shadow regions appearing as Glacial Lakes in EOS-04 FRS-1 VV Imagery

Resolution = 2.25 m

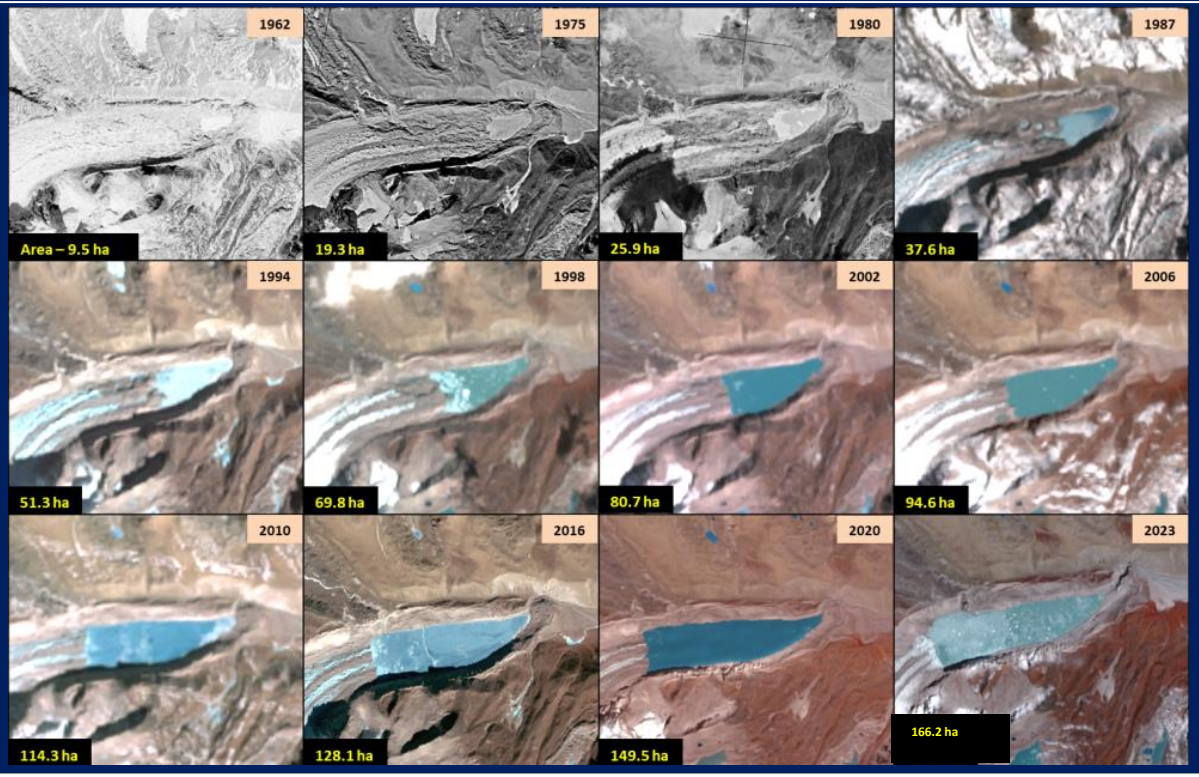
Imagery Type = SAR

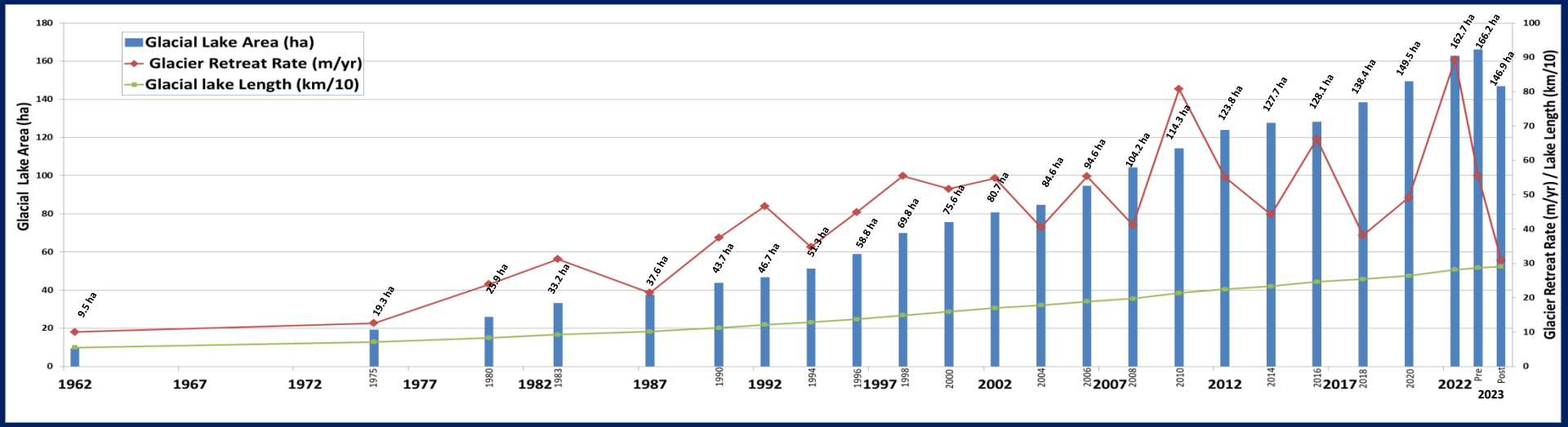
Monitoring of Glacier Lakes

Glacier Lake Identification and Mapping Using RS Data

Monitoring of Glacial Lakes

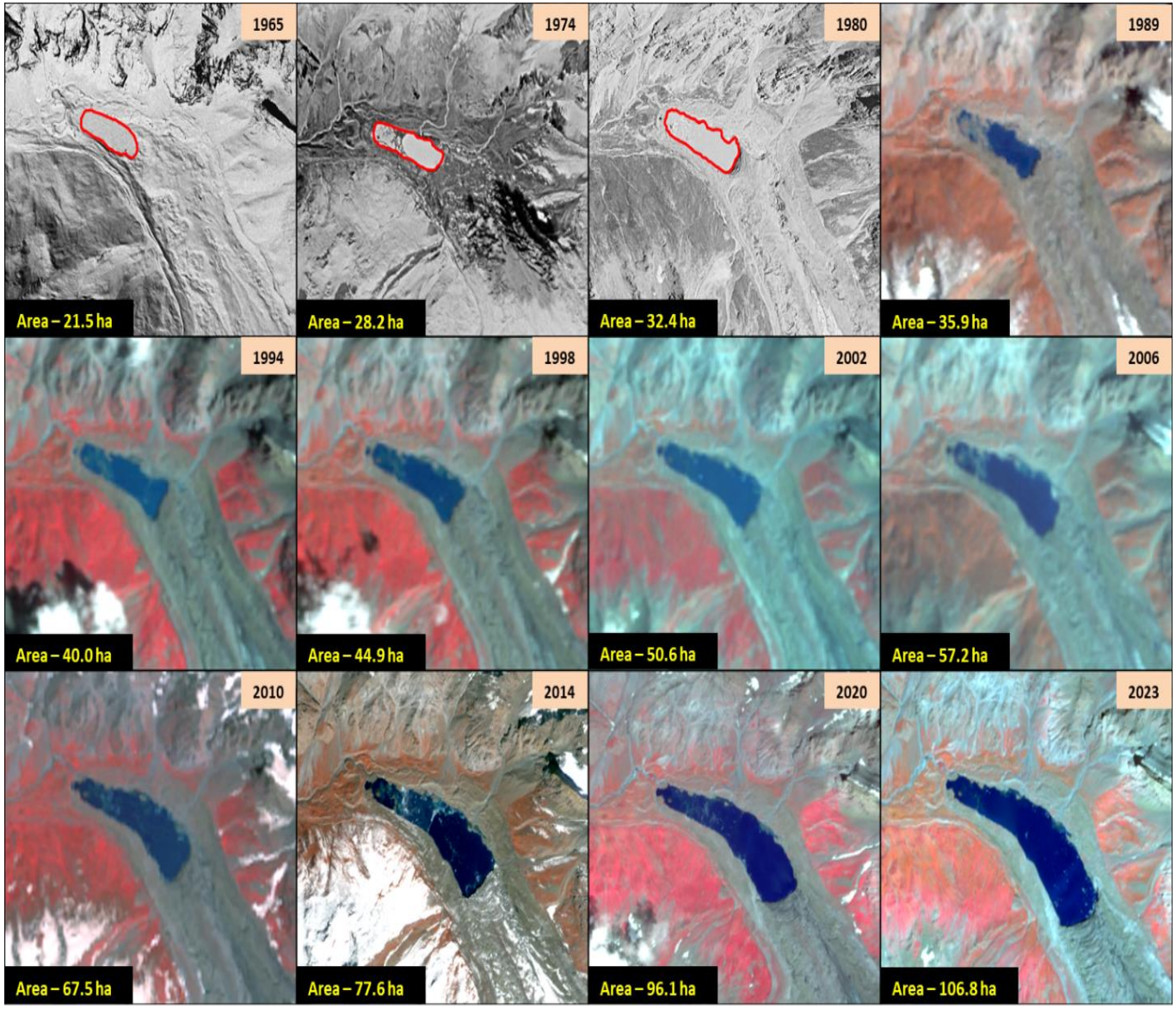
- Long term monitoring of South Lhonak glacial lake in Sikkim Sate,India

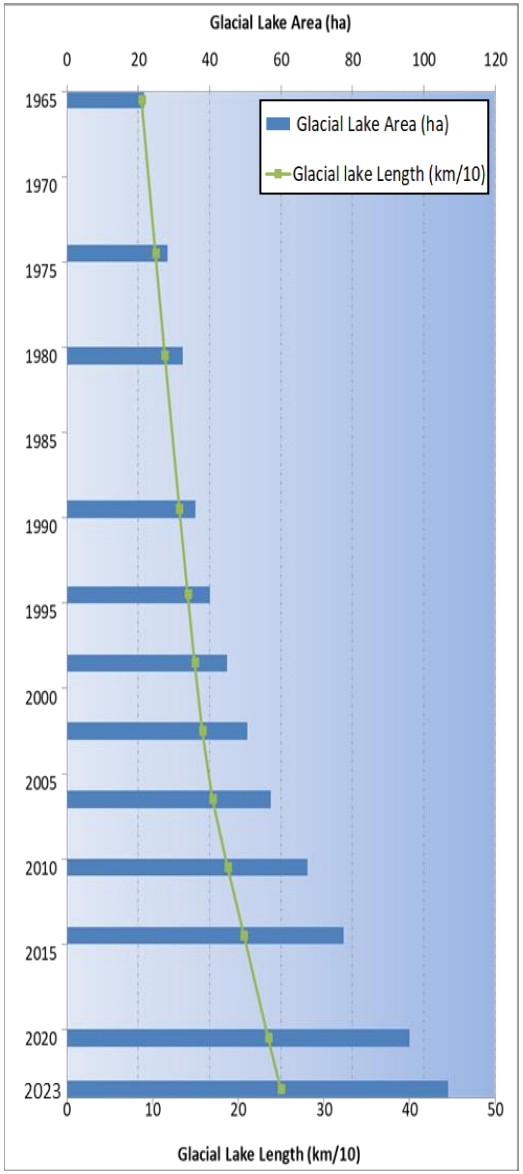




Glacier Lake Identification and Mapping Using RS Data

Ghepang Ghat Glacial Lake, India

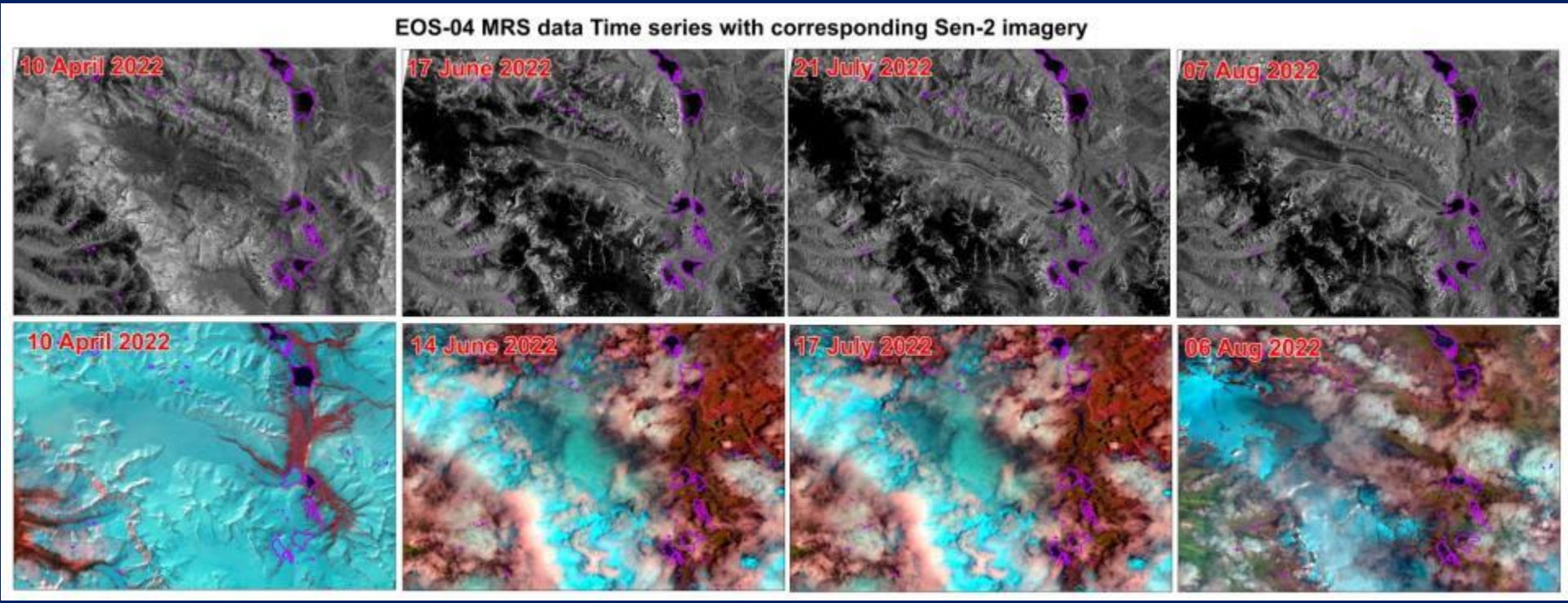




Glacier Retreat Rate: 30m/yr; Lake Expansion Rate: 400%

Glacier Lake Identification and Mapping Using RS Data

Glacial Lake (GL) monitoring using EOS-04 satellite data



EOS-04 Multi-temporal SAR imagery corresponding optical imagery showing Glacial Lakes in part of Lohit Sub-basin in Brahmaputra basin.

EOS-04
HH pol
MRS mode

Sentinel-2A/2B

Red: SWIR
Green: Red
Blue: Green
Glacial Lakes Outlines

Updated Database of Himalayan Glacier Lakes

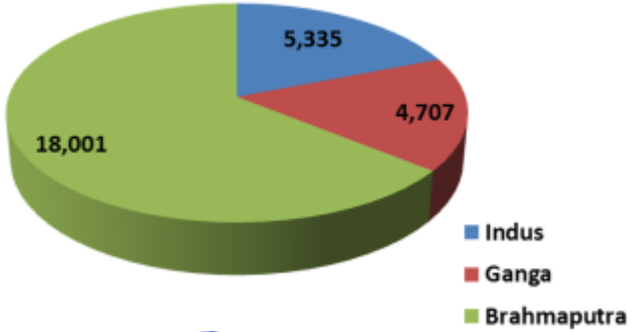
Glacier Lake Identification and Mapping Using RS Data

- Recent GLOF events like Pareechu(2005), Kedarnath(2013) created havoc for the people living in the downstream reaches
- These events indicate even small glacial lakes can have devastating effect when combined with extreme rainfall events
- It is important to have inventory of small glacial lakes in entire Himalayas

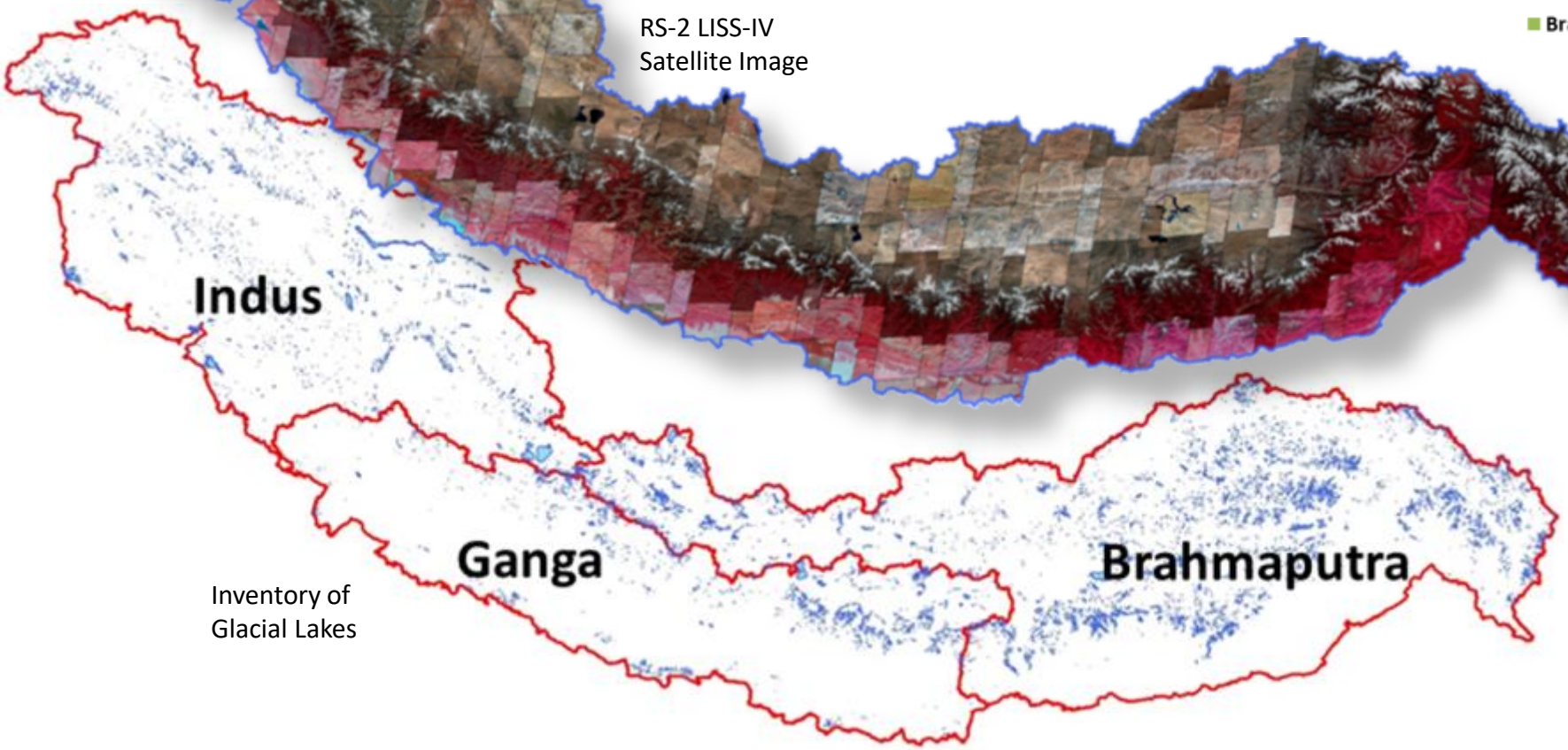
Glacier Lake Identification and Mapping Using RS Data

- Resourcesat-2 LISS-IV data (450 sub-scenes) covering entire study area were procured
- Inventory of 28, 043 Glacial lakes and water bodies (≥0.25 ha) along with 22 attributes

Under NHP



RS-2 LISS-IV
Satellite Image



Inventory of
Glacial Lakes

Glacier Lake Identification and Mapping Using RS Data

Attribute Data

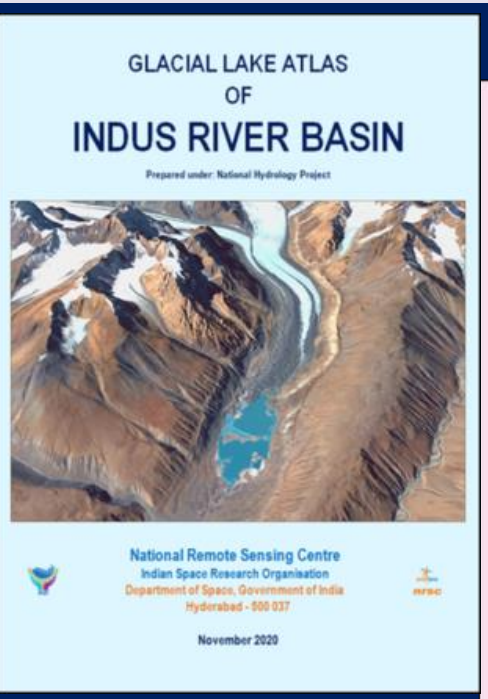
Hydrological, Topographical and other attributes for Glacial Lakes

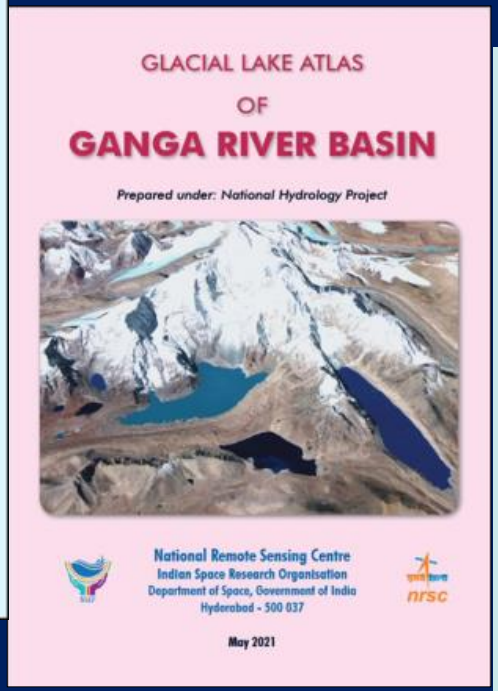
S.No	Database Fields	Type	Format / Unit	Lake Attribute
1	ID No	String	Text	0152H1103771
2	Toposheet 250K	String	Text	52H
3	Toposheet 50K	String	Text	52H11
4	Latitude*	Float	Decimal Degree	32.499
5	Longitude*	Float	Decimal Degree	77.547
6	Basin	String	Text	Indus
7	Subbasin	String	Text	Chenab
8	River	String	Text	Chandra River
9	Type (GL/WB)	String	Text	Glacial Lake
10	Name	String	Text	Samudra Tapu Lake
11	Glacial Lake Type	String	Text	M(e): End-moraine Dammed Lake
12	Surface Area	Float	ha	128.69
13	Length	Float	Km	2.381
14	Mean Width	Float	Km	0.821
15	Elevation	Integer	m (amsl)	4150
16	Aspect	String	Text	SE
17	Source of Database	String	Text	RS-2 LISS-IV
18	Date of Pass	Date	DDMMYYYY	05112016
19	Source of Elevation	String	Text	Cartosat DEM
20	Region	String	Text	India
21	State	String	Text	Himachal Pradesh
22	District	String	Text	Lahul & Spiti

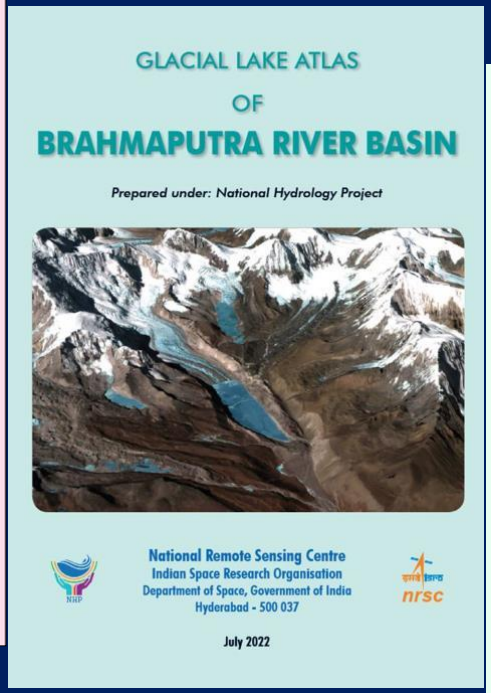
Glacier Lake Identification and Mapping Using RS Data

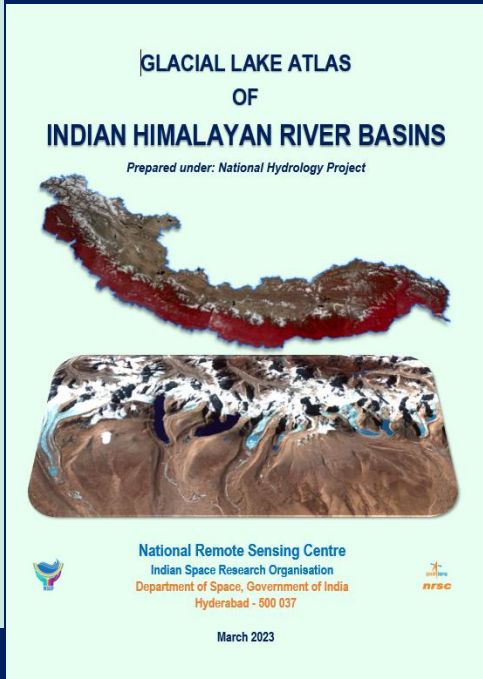
- **Using inventory of glacial lakes database, Glacial Atlases were released**
  - ✓ **Indus on 02-Dec-2020**
  - ✓ **Ganga on 29-Jun-2021 and**
  - ✓ **Brahmaputra on 05-Jul-2022**
  - ✓ **IHR on 16-Mar-2023**

Downloadable from
https://www.nrsc.gov.in/Atlas_Glacial_Lake
https://nhp.mowr.gov.in/HomeNew/NHPIndexnew.aspx#





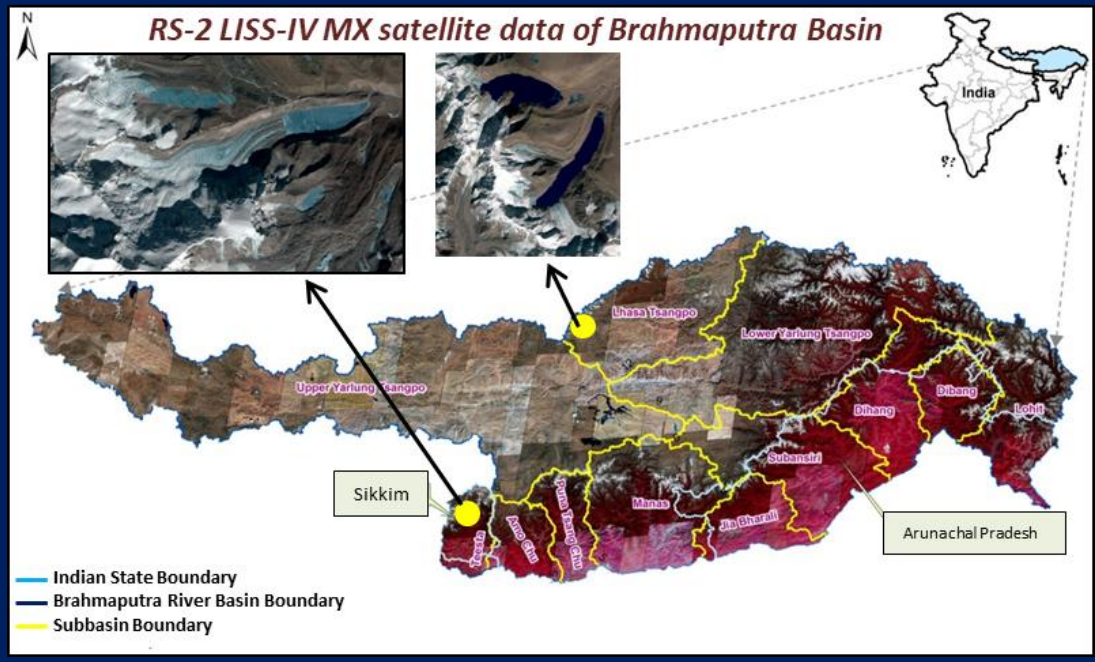


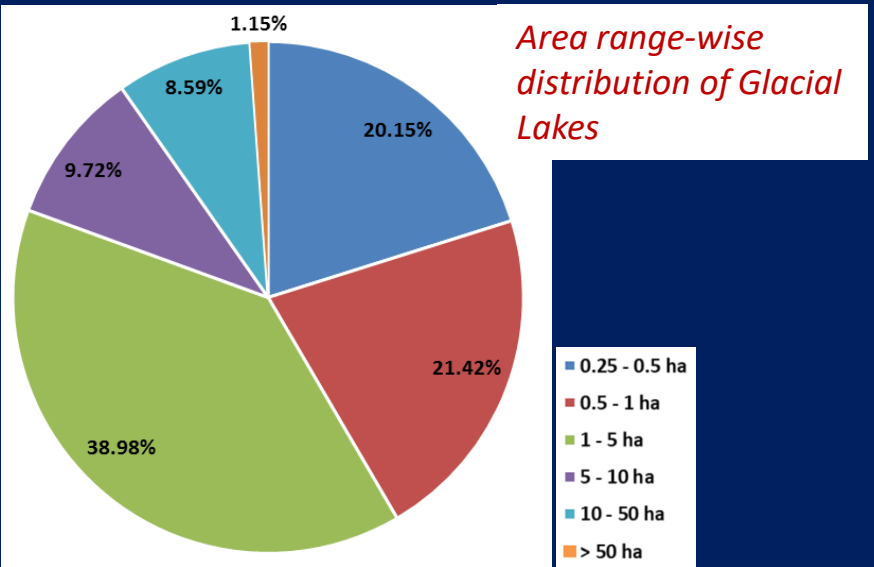


Glacier Lake Identification and Mapping Using RS Data

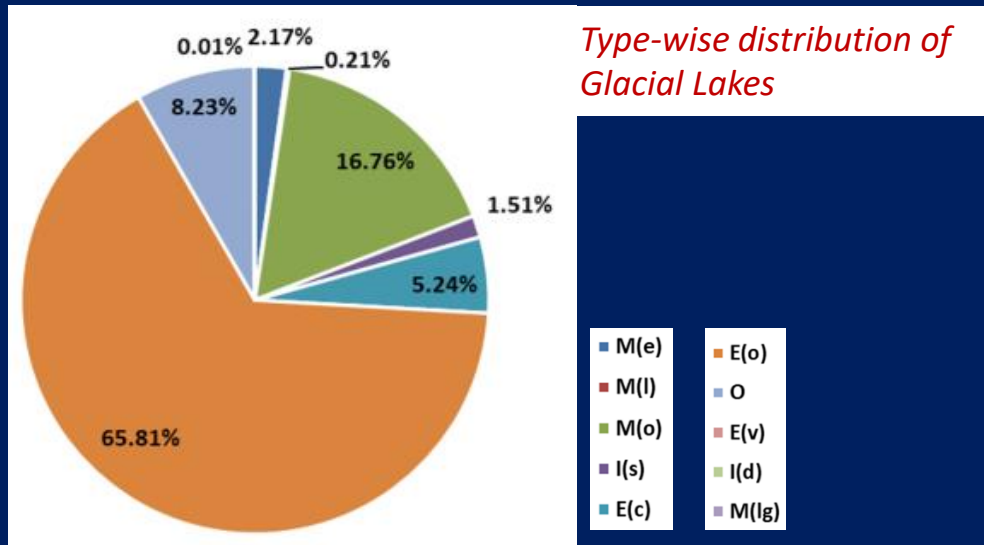
Table of Contents

Glacial Lake Atlas of Brahmaputra River Basin





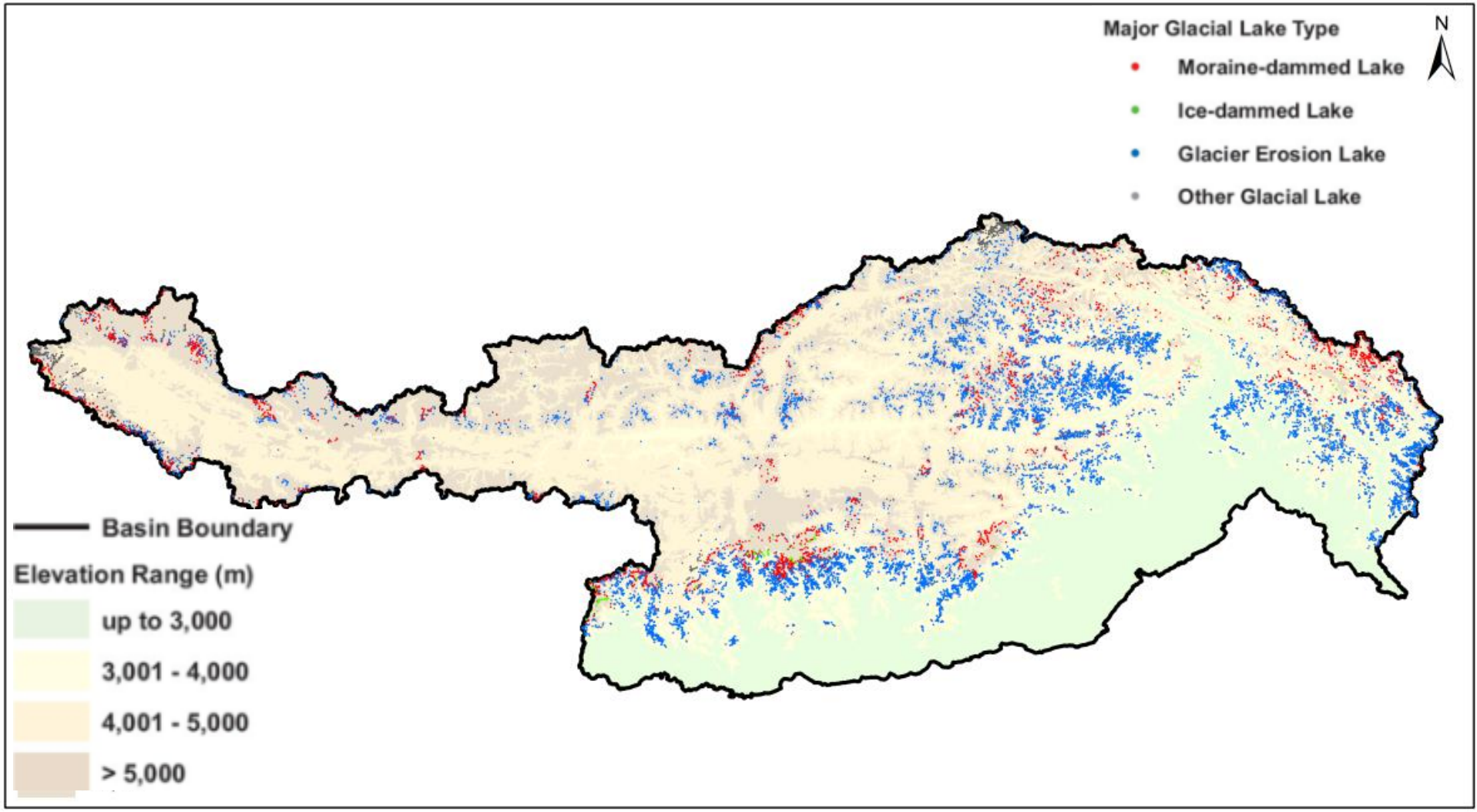
Area range-wise distribution of Glacial Lakes



Type-wise distribution of Glacial Lakes

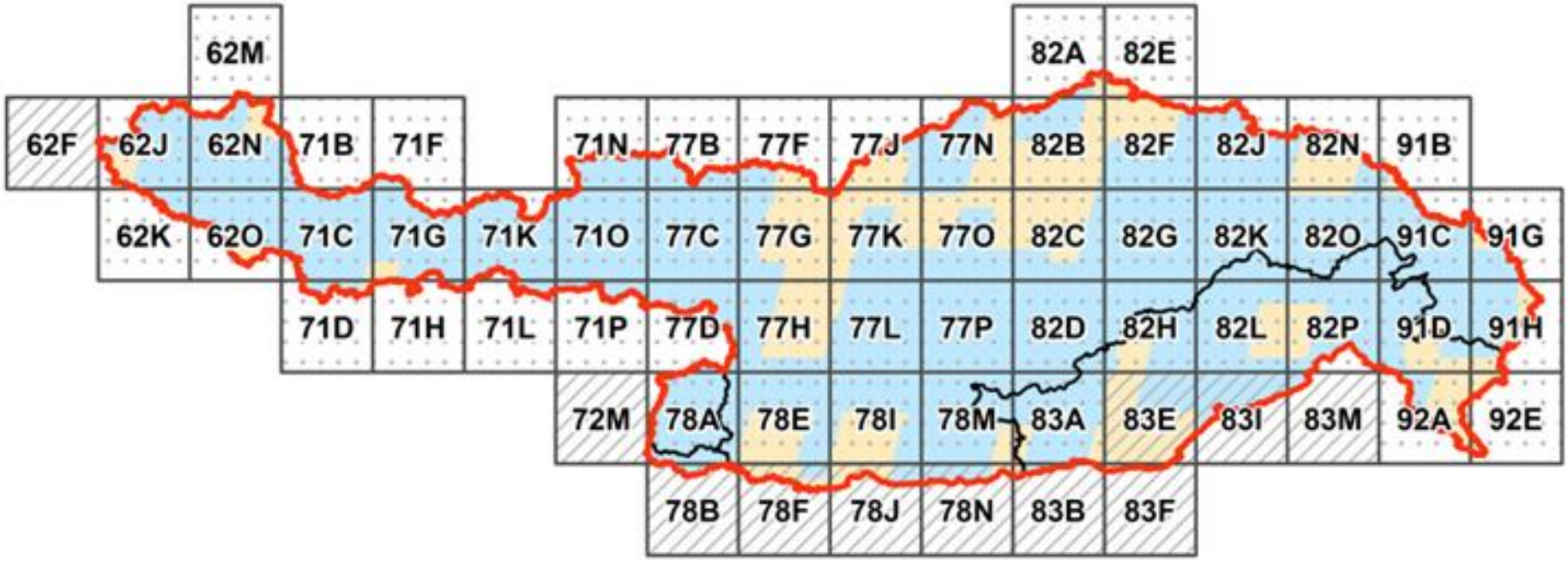
Glacier Lake Identification and Mapping Using RS Data

Types of Glacial Lakes in Brahmaputra Basin



Glacier Lake Identification and Mapping Using RS Data

Maps of Brahmaputra River Basin



Legend

Brahmaputra River Basin Boundary — Indian State Boundary

SOI 250K Toposheet No. (65)

Sheet Contain Glaical Lake (54)

Does not contain Glacial Lake (11)

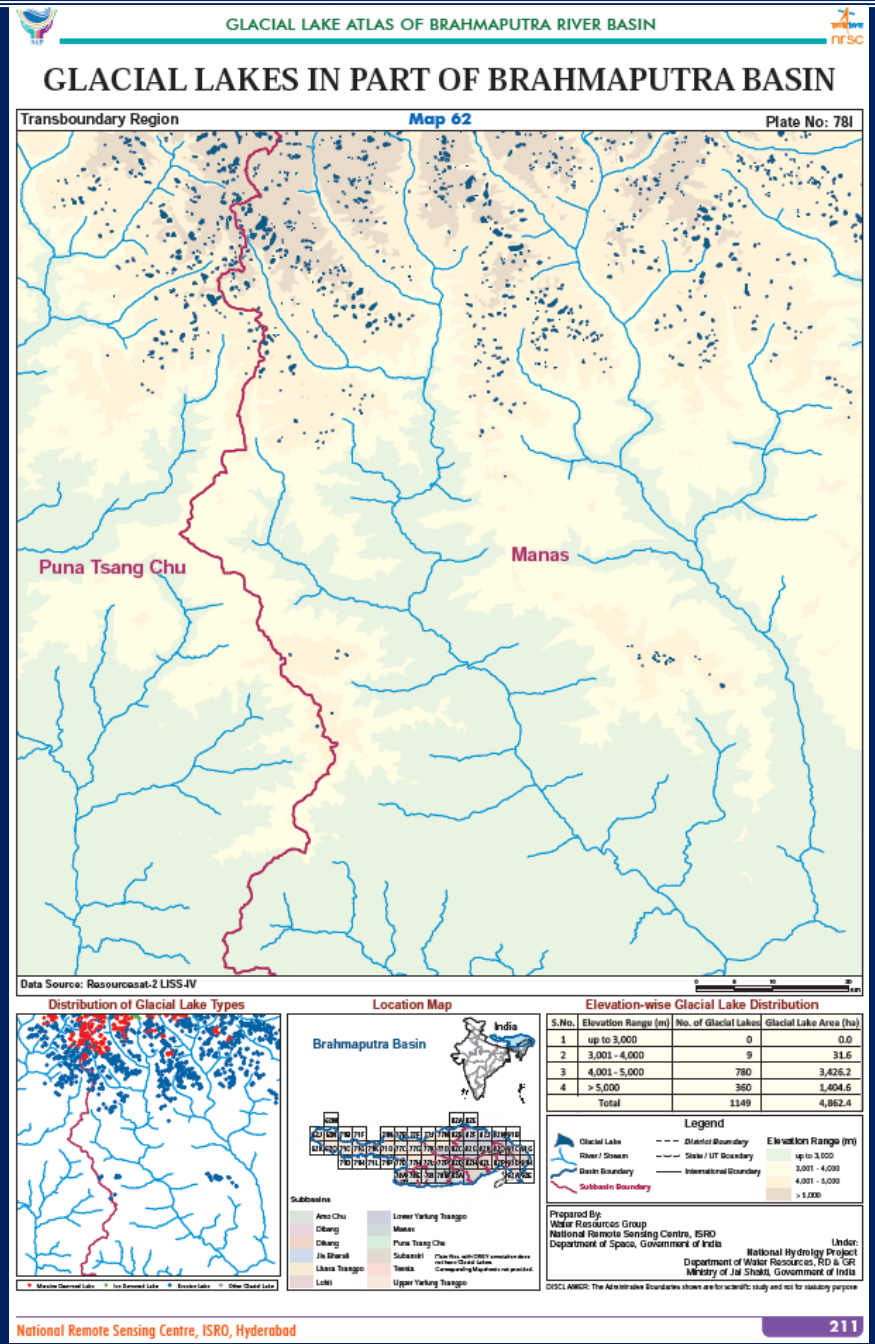
Year of Satellite Data Used

Prior to 2016

2016-21

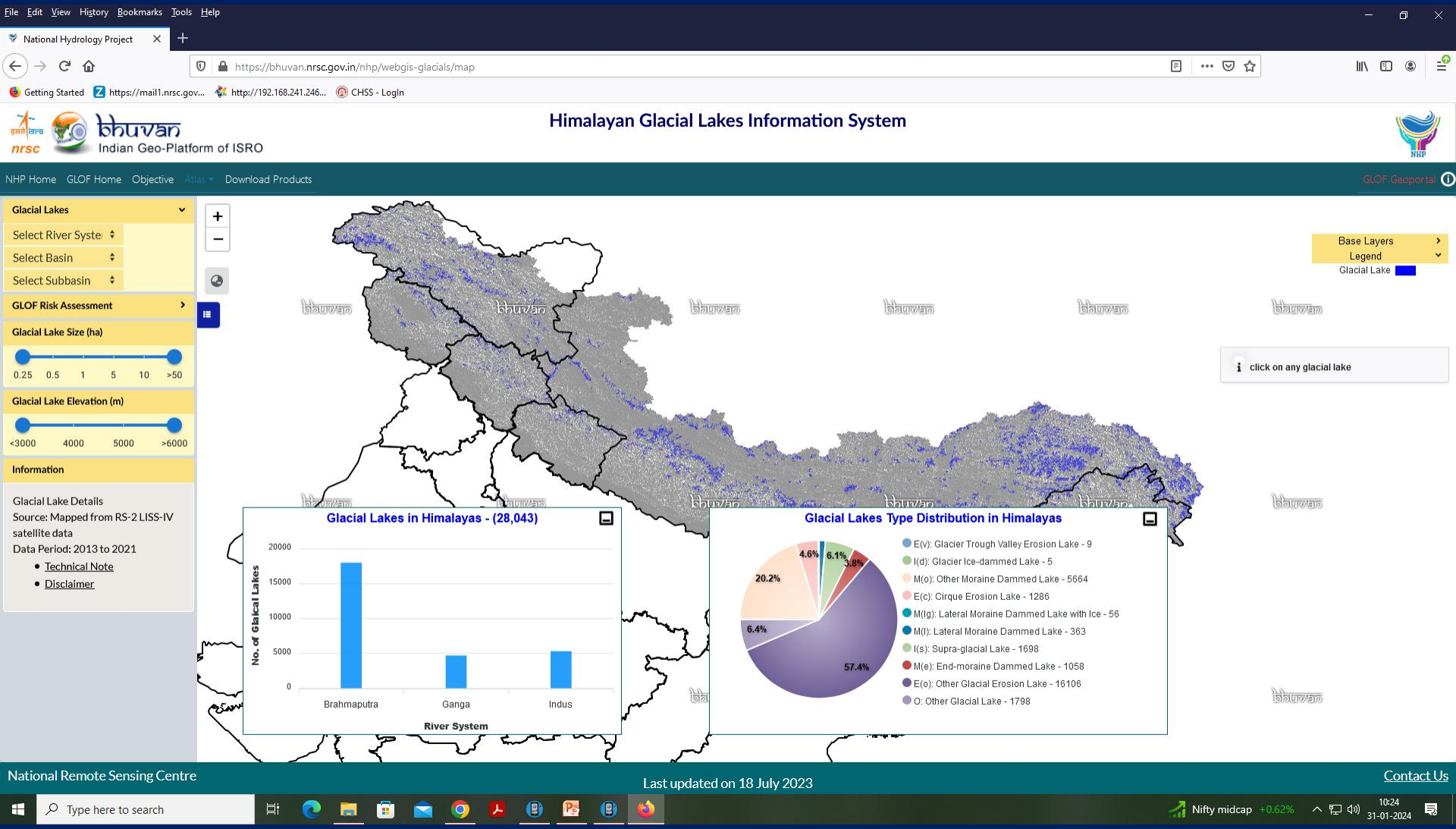
Glacier Lake Identification and Mapping Using RS Data

Sheetwise Statistics



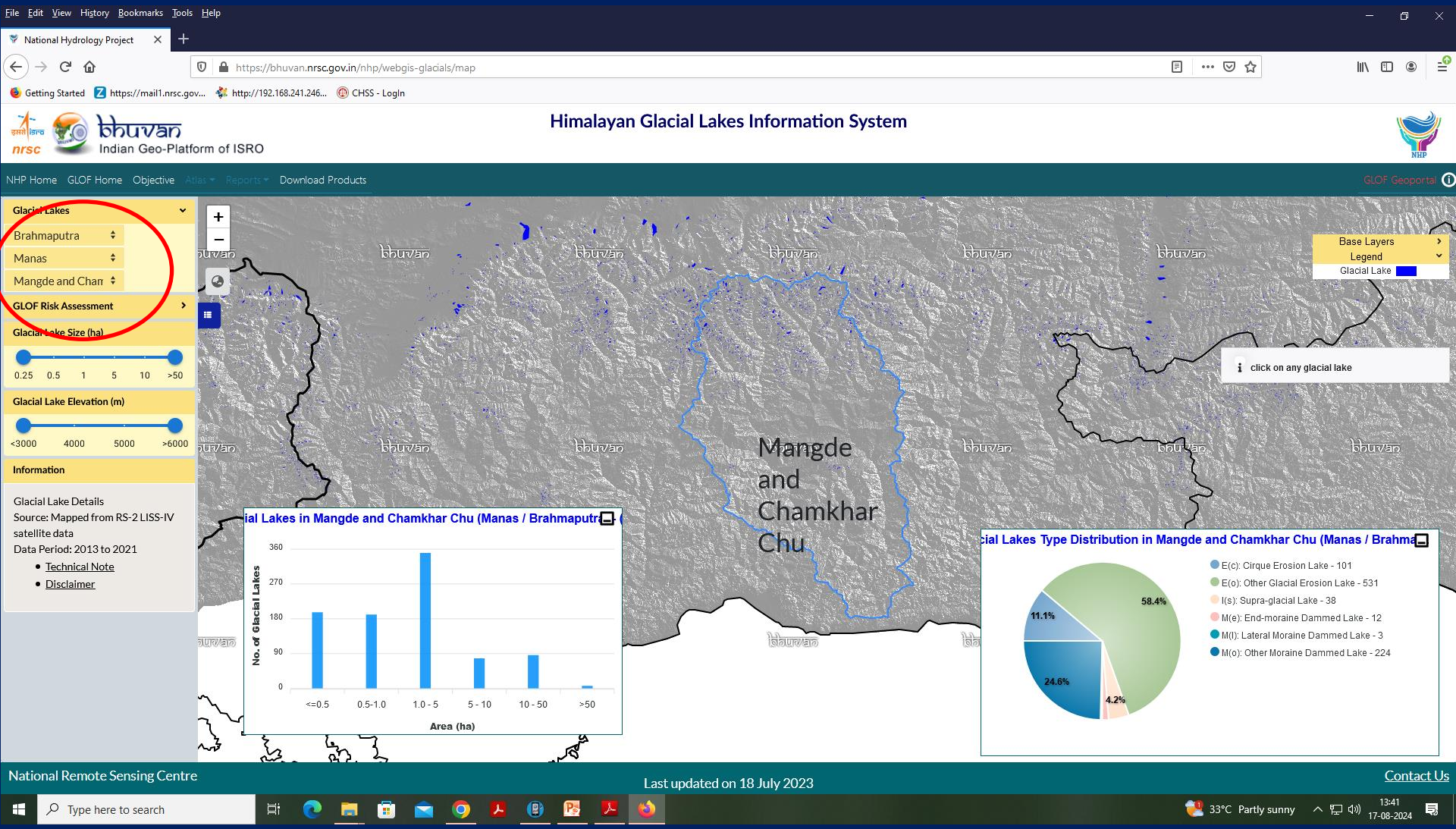
Part of Bhutan

Glacier Lake Identification and Mapping Using RS Data



https://bhuvan.nrsc.gov.in/nhp/webgis-glacials/map

Glacier Lake Identification and Mapping Using RS Data



https://bhuvan.nrsc.gov.in/nhp/webgis-glacials/map

Glacier Lake Identification and Mapping Using RS Data

Options for Risk Management of Glacial Lakes

Structural measures
Non-structural measures

	Reduction of Hazard	Reduction of Exposure	Reduction of Vulnerability
Short term measures	• Lower of lake level by Siphoning or pumping	• Evacuation (based on monitoring / Early warning)	
Long term measures	• Artificial drainage channel • Reinforcement / increase of height of dam • Enhancement of river cross section / protection from erosion	• Spatial planning according to hazard maps • Protective structures (e.g. retention or deflection dams)	• Information (capacity & data) • Institutional setup • Economic diversity • Disaster relief

Early Warning Systems

Outlet channel with reinforced dam reconstruction at the moraine dammed lake Laguna Cuchillacocha, Peru

Artificial Channel Enlargement of Imja Lake, Nepal, 26 September 2016

Source: Guidelines on Management of GLOF

THANK YOU